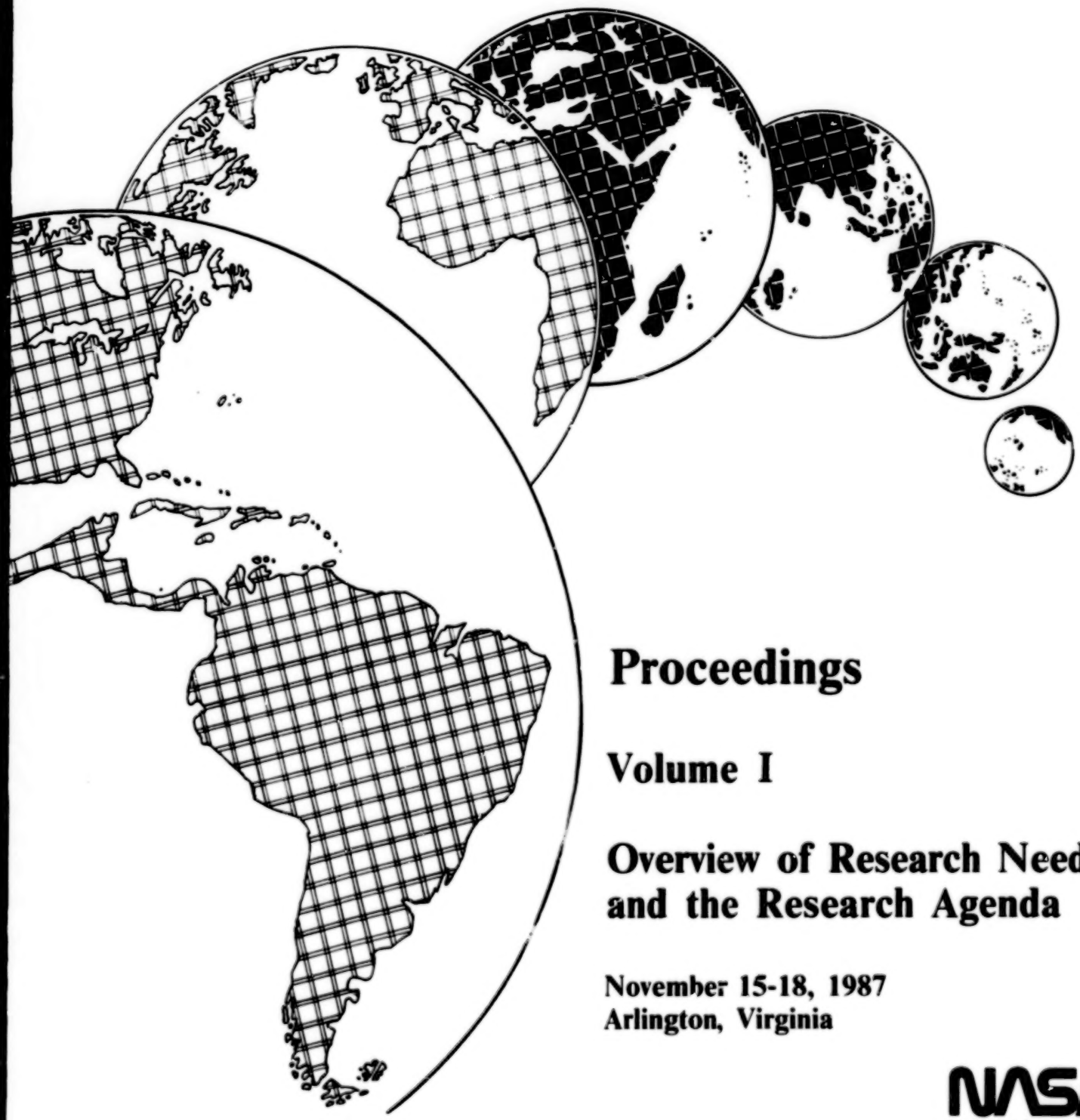
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International Geographic Information Systems (IGIS) Symposium: The Research Agenda



Proceedings

Volume I

Overview of Research Needs and the Research Agenda

November 15-18, 1987
Arlington, Virginia

NASA
National Aeronautics and Space Administration

COMPLETED

INTERNATIONAL GEOGRAPHIC INFORMATION SYSTEMS (IGIS) SYMPOSIUM

The Research Agenda

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Dr. Robert T. Aangeenbrug, Co-Editor
Yale M. Schiffman, Co-Editor

Convened by the

Association of American Geographers

In Cooperation with
National Aeronuatics and Space Administration
Bureau of Land Management
U.S. Army Engineer Topographic Laboratories
National Oceanic and Atmospheric Admininistration
U.S. Geological Survey
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Bureau of the Census
Urban and Regional Information Systems Association
American Congress on Surveying and Mapping
World Computer Graphics Association
American Society for Photogrammetry and Remote Sensing
Marine Technology Society
Centre for Earth Resource Management
National Governor's Association
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PREFACE

These proceedings contain a selection of papers presented at the Association of American Geographers' (AAG) International Geographic Information Systems (IGIS) Symposium which was held at the Hyatt Regency Crystal City Hotel in Arlington, VA, on November 16-18, 1987. The papers cover a wide variety of subject areas related to the conference theme, "The Research Agenda," and describe the current status and future direction of geographic information systems and their application to a number of resource management concerns.

The symposium brought together professionals in such diverse fields as remote sensing, geographic information systems, data base management systems, information systems, urban and regional planning, fish and wildlife management, geography, cartography, artificial intelligence, systems analysis, and resource management. The speakers and audience had an international flavor with representatives from South America, Africa, Europe, Canada, Asia, and the United States. In all, nearly 500 professionals met to exchange information and ideas regarding the role and the research needs and agenda for the development of the next generation of geographic information systems. Fifty exhibit booths displayed the latest geographic information systems hardware, software, and services.

On Monday, November 16, nearly all of the federal agencies involved in the design and development of GIS presented their respective views on agency needs in a plenary session chaired by Ronald F. Abler, National Science Foundation. The policy perspective was provided by Paul Huray, Office of Science and Technology, and Robert Lee Chartrand, Congressional Research Service. The National Aeronautics and Space Administration, the Bureau of Land Management, the National Oceanic and Atmospheric Association, the U.S. Geological Survey, the Defense Mapping Agency, the USETL, the Federal Emergency Management Agency, the Bureau of the Census, the U.S. Department of Agriculture/Forest Service, and the Environmental Protection Agency were all represented. That afternoon, a plenary session chaired by David Cowens, University of South Carolina, explored the GIS research agenda from the perspective of the scientific community.

On Tuesday, November 17, a panel chaired by Michael Dobson, Rand McNally and Company, presented an overview of the trends in hardware and software development of GIS. This plenary session provided the industry view of where GIS seems to be heading. On Wednesday, November 18, a plenary session chaired by Duane Marble, Ohio State University, explored the cutting edge of GIS development in terms of spatial analysis and artificial intelligence. The final plenary session examined some of the practical aspects of GIS management and implementation in a session chaired by William J. Craig, University of Minnesota.

Three keynote addresses were given on Tuesday, November 17,

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at a well attended luncheon. Roger Chorley, President of the U.K.'s Royal Geographic Society, Dallas Peck, Director of the USGS, and Roger Tomlinson, President of the Canadian Association of Geographers, gave enlightening perspectives on where GIS has been and what is in its future.

The keynote addresses, as well as the plenary sessions, can be found in Volume I.

The meeting closed on a positive note, indicating that there was, indeed, a need to continue dialog by specialists from this wide array of interests. The emphasis should be on improving the communication between the user community and the software, hardware, and analytical support specialists in the field. Thus, this meeting serves as the starting point for a continuing series on the subject.

The interdisciplinary oriented symposium provided a forum for presenting and discussing scientific works in the areas of energy resource management, remote sensing, geographic information systems, other georeferenced data systems, environmental analysis, and applied systems research. Nearly 125 scientists, engineers, planners, and other professionals from around the world contributed to these proceeding.

The proceedings have been organized along subject lines rather than in order of presentation. The editors felt the information would be more useful to the reader if it were organized in this fashion. In Volume I, these papers examine a general overview of the state of the art. Volume II examines the technical issues. In Volume III, the papers explore the topic from an applications focus. Many papers also explore the integration of remotely sensed data with other georeferenced data systems. The proceedings clearly reflect the trends to integrate remotely sensed data with a number of different georeferenced data systems and illustrate an emerging interest among a number of different specialties for use of these integrated data systems in environmental assessment and resource management.

There also appears to be a strong interest in developing countries for the acquisition and utilization of low to moderate cost hardware and software. It is the opinion of the editors that this symposium brought together a mix of professionals--the providers of hardware and software and the users--that needed to communicate with one another. The conference provided the proper setting for an exchange of information which will serve to improve the understanding of all the needs in this emerging field.

June 1988

Dr. Robert T. Aangeenbrug, Co-Editor
Yale M. Schiffman, Co-Editor

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The Association of American Geographers (AAG) would like to acknowledge the contributions of the Science Advisory Committee consisting of Ronald F. Abler (National Science Foundation), Ray Arnold (NASA), Penman R. Gilliam (Defense Mapping Agency), Marcio Barbosa (Instituto de Pesquisas Espacials), John Bossler (Ohio State University), Kurt Brassel (University of Zurich), Robert Lee Chartrand (Congressional Research Service), David Clark (NOAA/NGDC), David Cowen (University of South Carolina), Will Craig (URISA), Doyle Frederick (USGS), Joan Hock (NOAA), Paul Huray (Office of Science and Technology), Duane Marble (Ohio State University), Robert Marx (Bureau of the Census), Jean Claude Mueller (ITC), Bruce Opitz (U.S. Army Engineer Topographic Laboratories), David Rhind (Birbeck College), Ronnie Savegear (ISPRA), Terence Smith (University of California), Duane Sonnenburg (BLM), Lowell Starr (USGS), Waldo Tobler (University of California), and Lofti Zadeh (University of California). The Committee provided useful guidance to AAG's staff and support contractors, Nancy and Yale Schiffman of E.H. Pechan and Associates, Inc.

AAG would also like to acknowledge the Program Advisory Committee for their assistance in developing the sessions. This committee consisted of Ray Allison (USDA), Lorraine Amico (National Governors' Association), Bob Barker (SPOT Image Corporation), Frank Baxter (ACSM) Hugh Bloemer (Ohio University), Walter Boge (ASPRS), Fred Broome (Bureau of the Census), Nicholas Chrisman (University of Washington), Jerry Dobson (Martin Marietta), Ken Dueker (Portland State University), Michelle Ellrod (Marine Technology Society), Earl Epstein (NOAA), Sheila Frye (NOAA), Tom Gilding (National Agricultural Chemicals Association), Barry Glick (Spatial Data Sciences Inc.), Michael Goodchild (University of Western Ontario), Lars Greczy (U.S. Army Engineer Topographic Laboratories), Mason Hewitt (EPA), Robert Jaske (FEMA), Dennis Johnson (U.S. Forest Service), Richard Kott (EOSAT Corporation), Cliff Kottman (DMA), Millington Lockwood (NOAA/NOS), James Merchant (University of Kansas), David Moody (USGS), Richard Mroczynski (EOSAT Company), Denny Parker (Colorado State University), Liz Porter (U.S. Army Engineer Topographic Laboratories), Carl Reed (Delta Systems), Vincent Robinson (University of Calgary), Rolf Schmitt (U.S. Department of Transportation), Duane Sonnenburg (BLM), Theodore Steinke (University of South Carolina), Henry Tom (National Bureau of Standards), William Ubbens (USDA), Tom Usselman (National Research Council), and Fred Wood (Office of Technological Assessment).

AAG thanks those members of both committees who devoted their time and energy to the review and final selection of papers that were presented at the symposium.

AAG also acknowledges the sponsors--the National Aeronautics and Space Administration, the Bureau of Land Management, the U.S.

Army Engineer Topographic Laboratories, the National Oceanic and Atmospheric Administration, and the U.S. Geological Survey--who provided in-kind services, financial support, and contributed to the technical substance of the program.

Finally, special appreciation goes to the National Aeronautics and Space Administration which is making the publication of these proceedings possible.

June 1988

Dr. Robert T. Aangeenbrug, Co-Editor
Yale M. Schiffman, Co-Editor

LUNCHEON PRESENTATIONS

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LUNCHEON ADDRESSES

GIS Research and Development: A U.K. Perspective. Lord Roger Chorley, President, Royal Geographic Society, United Kingdom

I am not a geographer, and I am not sure what geography is--what is the common thread which binds together all the disparate elements which commonly come under the heading "geography" ? What, for example, do physical geography and human geography have in common? Is not geomorphology more appropriately dealt with as part of geology? And is not human geography already encompassed in economics and sociology?

In your country I understand that for the most part you have answered this question by doing just that: putting human geography with the social sciences and physical geography with the earth sciences. For my part, looking at this problem from the outside, I cannot help having a feeling of uneasiness; my instincts tell me that splitting the subject in this way may mean losing an important dimension. That missing dimension is perhaps the missing thread that I am looking for.

Exactly 100 years ago the RGS helped found and fund the first senior university appointment in geography. It was at Oxford and it was held by Halford Mackinder, probably the most influential and distinguished of British academic geographers. In 1887 he lectured to the RGS "On the Scope and Methods of Geography." "Can," he asked, "geography become a discipline instead of a mere body of information?" He went on to define geography as "the science whose main function is to trace the interaction of man in society and so much of his environment as varies locally." One can widen that a little by saying that geography is concerned with why different localities are what they are. Implicit in this is the whole range of attributes, physical and human, of a locality and their interaction with each other.

This, it seems to me, is beginning to provide the binding force I am looking for. One of my predecessors, Sir Charles Close, put it like this: "One source of our strength is that we have no narrow restricted view as to the context of our subject... " And it is that breadth, the way it spans the arts and sciences, which, for example, attracts university students to geography.

Nevertheless, while we can argue that the strength of geography is its breadth and its synthesizing role, it is also for that very reason an undeniable weakness. Subjects or disciplines which are neatly self-contained with clear boundaries are much easier to handle by administrators and others. Anything, therefore, which helps to bind the disparate elements of

geography together and also to bind it to the sciences is in my view important.

What, you may well ask, has all this got to do with GISs? The answer, I think, lies in the fact that GISs add a new dimension to spatial analysis. It makes geography, at least in the higher echelons, a more readily quantitative subject and one which can bind together the disparate elements. I think that it was Ron Abler who drew the analogy with the effect on science of the invention of the microscope and telescope, and he also drew an analogy with the revolutionary effect of the invention of the printing press on the dissemination of knowledge. Other analogies are the effect of the invention of the micrometer on precision engineering and of the computer on economics. All these inventions are tools which enable things to be measured. And that is what a GIS is: a tool which enables us to explore and measure spatial relationships--to measure the interaction between all these disparate elements, whether physical or socio-economic, which makes up geography.

Of course, the importance or perhaps more strictly the value of being able to measure things is greatly enhanced if they enable us to make reliable and preferably quantified and useful predictions. Here the relevance of GISs is in our potential ability to model spatial phenomena, whether environmental or socio-economic, or indeed both. In our field, as in economics, this is particularly difficult because of the complex and often fuzzy inter-relationships. You may perhaps recall Banquo's anxious entreaty to witches in Macbeth, "If you can look into the seeds of time and say which grain will grow and which will not, speak then to me."

However, I am perhaps jumping ahead a little. At the present time one can't help feeling that at this formative stage GIS technology is a solution looking for problems to solve. There is a lot of fascinating and healthy exploration going on--the great range of subjects covered by this conference testifies to that. What is now important, and is certainly happening in North America, is the development of day-to-day applications. This raises a variety of quite different issues. While the technology is a necessary condition for the handling of spatial data and carrying out spatial analysis, it is not a sufficient condition. I would add, in parenthesis, that I also take it for granted that in five years we will look back on today's technology as being decidedly slow, expensive, and primitive in its capabilities.

What, then, are the other conditions which need to be satisfied if we are to get added value which is useful to decision makers and administrators? The problems are that:

- There is enormous diversity of spatial information.
- There is an equally large diversity of users and uses.

- o Many different organizations but principally organs of Government are responsible for collecting it.

- o Many types of spatial data are used for more than one purpose and by more than one user.

In short, the picture is one of dissuasiveness and lack of coherence. They suggest we need to achieve three things if we are going to get widespread use of the GIS tool:

1) The data needs to be available, and in digital form.

2) If different data sets are to be linked--and much of the benefits of a GIS depends on linking data sets--then they need to conform to certain standards.

3) The ordinary day-to-day user of spatial data needs to know how a GIS can help him.

Data Availability

It may seem otiose to remark that digital data needs to be available. But the fact is that converting data to digital form --I am thinking of topographic maps data and also utility and local government property data--is extremely costly and difficult to automate. Moreover, these are institutional problems-- officials regard data as being their data. There are problems of confidentiality regarding personal data, and there is a lack of appreciation of the need for data to be highly desegregated.

Data Standards

Even if data is available, it must meet three further requirements to be capable of being linked to other data:

- o All spatial data which relates to areas needs to be made available to a common spatial unit, and the unit needs to be small, e.g., in the UK, unit post-codes for socio-economic data.

- o Each item of spatial data, each spatial unit, needs to be labeled with its location to a common standard, e.g., the national grid coordinator.

- o In order that data can be exchanged--so that you can use my data on your computer system--there need to be common definitions of attributes, common data exchange standards, and the data needs to be tagged with information on its quality and temporal information, for times series information is often very useful.

The subject of standards is in the UK preeminently a field for Government, both as the main provider of national data sets

and as "legislator." I am well aware of the Herculean task performed here by the Moellering Committee on cartographic standards. It has provided a useful lead in the UK, and I pay tribute to its work.

There are many other aspects of standards--I am using the word in a rather loose sense which I could dilate on at some length--and risk losing your attention. I will restrict myself to two points.

First, in many fields of activity there are enormous advantages in a commonality of approach. For example, it is a great advantage to society if we drive on the same side of the road (notwithstanding that you drive on the right and we on the left); or that we all spell words the same way. But while we can legislate on which side of the road we drive, we cannot legislate about spelling. The fact that we cannot--as a practical matter--enforce such things is a drawback. We can promulgate codes of practice but they will, I suggest, be ineffective unless they broadly conform to general practice. In other words, we need to proceed by way of <u>de facto</u> standards. It was for that reason that we recommended for the UK the unit post code (similar to your zip code but only fifteen houses) as the basic spatial unit for socio-economic data. And that was why we attached great importance to the result of the next Census being based on unit post codes--because the Census data is so widely used it can help to achieve a <u>de facto</u> standard.

These sorts of problems are difficult enough in a national context. They become much more complex and give rise to all sorts of institutional problems when we start to think about collecting and exchanging spatial data on an international scale. Here I would like to mention the initiative of the IGU on global database planning and design for the IGBP program. If the ultimate objective is a coherent earth description whose unit is not just to a single agency or discipline, this then is a major field for cooperation and a field which is positively bristling with problems. I, therefore, warmly welcome the IGU's initiative in addressing these issues. I wish Roger Tomlinson, who is with us today and who is spearheading this, every success in a difficult task.

<u>Awareness, Education, and Training</u>

I come next to my third and last category of things that need to be done: getting across to the ordinary user why the new technology is relevant.

One of the aspects of handling GI that struck my committee most was the lack of awareness of the capabilities of the new technology in adding value to GI. Other studies in the IT field generally have reached similar conclusions. A big promotional effort is required at various levels, crucially at the Chief Executive level, and in local Government also at chairman level.

But I do not ignore the fact that there are often serious pockets of indifference to IT at a middle management user level, and a tendency to think compartmentally--perhaps "departmentally" is the right word. With awareness goes the need for much greater effort--at present it is minimal--in education and training.

Human and Institutional Problems

I have been talking so far mainly about the rather tangible barriers to using GISs. There is one other intangible set of barriers. There is much evidence from both at home and abroad that the major difficulties in successfully introducing Geographic Information Systems are as much human and institutional as they are technical or a lack of data of the right sort. In a forum such as this I think it is worth spending a little time on this.

- o Managing the information resource.
- o The human factor.

Managing the Information Resources

The first lesson from information systems generally is that information should be regarded as a corporate resource.

Second, advocating a corporate strategy for information is not the same as saying that information should be centrally held. One of the lessons from experience is that the custodian of a data set or database should have a long-term interest in the information; only in this way will we have the confidence in the data and keep it up to date.

Human Factor

Finally, and of great importance, account needs to be taken of the human factor. Major new information systems will mean major changes in the way people use information, and how they do their jobs.

Let me reinforce this point with a quotation from one of the most perceptive writers on this subject. He said, "There is nothing more difficult to arrange, more doubtful of success, and more dangerous to carry through, than to initiate a new order of things... . Men are incredulous, never really trusting new things unless they have tested them by experience." That was Machiavelli, writing about fifteenth century Florence.

Conclusions

This is perhaps a suitable point at which to bring my remarks to a close. We spend hundreds of millions of pounds or dollars in collecting geographic data, but we are only scratching the surface in getting added value from it by using the tools

which are now at our command. The technology is the easy part. We have the capability to do things with data which we have never been able to do before. The problem is to get people to use it--the managers and the decision-makers.

Would it be unfair to suggest to an elite audience such as this that we should be putting as much effort into thinking about how we can develop the market--stimulate the demand--for this new tool we have invented, as the effort we put into the technology of GISs?

Of course new tools, as we know from the history of economic development, have been crucial in advancing human progress. But the market has to be created for their use--and no more so than in GISs.

And the geographer, as I said in my opening remarks, is someone who is used to rubbing shoulders with many other disciplines. This world could and should be your oyster.

GIS Development and Support for the Earth Sciences. **Dallas Peck**, Director, U.S. Geological Survey, U.S.A.

For over 100 years, the Geological Survey has collected data on the water, mineral, and energy resources of the United States. These data and analyses have been distributed in map and report form and, since the introduction of computing technology, in digital form on magnetic and other machine readable media as well. Major computerized databases include those on base category mapping, geographic names, water resources, minerals, coal, and land use/land cover. In the early 1970s, interactive geographic information systems (GISs) were developed which allowed overlaying and linking these, and other data layers, for analysis and graphics display.

GIS technology has grown rapidly and USGS has established shared, interdisciplinary, regional GIS research and development laboratories at its headquarters in Reston, Virginia; and in field locations in Denver, Colorado; Menlo Park, California; Sioux Falls, South Dakota; and Anchorage, Alaska. These facilities are accessible to 60 percent of USGS personnel and provide a unique environment that permits day-to-day contact, observations, informal discussion and technical consultation among specialists in geology, geophysics, hydrology, geography, cartography, and computer science. GIS capability is also provided at about 50 smaller field offices and to other locations via telecommunications. These facilities have supported numerous cooperative programs with other federal, state, and local agencies, as well as the earth-science programs of the USGS.

Future trends and activities include advanced database design and additional database development; the development of federal standards for the exchange of spatial data in digital

form; the application of artificial intelligence and knowledge based systems for spatial analysis; the use of supercomputers for three-dimensional modeling and "visualization"; the wider use of low-cost, "personal" GIS capability; an increased role in international climate programs; the use of optical disk and CD-ROM for archiving and distributing digital data; and continued support for interagency cooperative activities. One special function is the co-sponsorship with the National Academy of Sciences and the Association of American State Geologists of a national GIS symposium in Denver, Colorado, on September 26 to 30, 1988.

Summary. **Roger Tomlinson**, President, Canadian Association of Geographers

I have just gone through the routine of trial by fire. This is very interesting. In the spirit of international cooperation and free trade, they have asked an Englishman who lives in Canada and who owns a company in the United States to say thank you to the two speakers that we have just had. This really is my way of a vote of thanks rather than a summary of their interesting talks.

I bring you greetings from your cousins to the north, from the Canadian Association of Geographers who are absolutely envious that you can hold such an excellent meeting on GISs and get 500 people to attend. This is an excellent meeting, and I was very impressed by the quality and the scope of the papers.

Bear in mind that only two weeks ago, there was a meeting on GISs in San Francisco where 1200 people attended. If I look back over this year, there has been one GIS meeting almost every two weeks for the past two years, and it looks like there is going to be another one for every two weeks in the next five years.

There is an incredible amount of energy and drive in this field, an incredible amount, and it is represented here in this room today. The organizers and the American Association of Geographers ought to be applauded for having the wisdom and the ability to put this meeting together. It is a good meeting.

It is very interesting to note that the major players are here. Lord Chorley introduced himself as an accountant. He was an accountant who was a member of a very critical ordinance survey committee in Britain that was considering the whole future of the equivalent of USGS national mapping. He was a member of the Remote Sensing and Digital Mapping Committee for another two years. He was chairman of the Committee of Enquiry in the Geographic Information System, and getting deep into each of those areas each time. Some accountant. That's a major player by any standards in any nation.

And Dallas Peck next to me represents the U.S. Geological

Survey whose work he so ably illustrated. When the International Geographical Union was invited to look at the activity and spatial data handling in the U.S. Geological Survey in 1976, they already had 52 GIS special information systems and at that time were already committed to 1.7 thousand terabits of data in spatial form. That was the level that they anticipated reaching by 1982. I believe that the estimate was exceeded, and they have more now.

These are major players. Very major players. I guess what we have here then is the Geographic Information System equivalent of the Washington power lunch. And it is a pleasure to be able to say thank you for two excellent presentations and to invite you all to thank them for being with us today.

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PLENARY SESSION 1. GEOGRAPHIC INFORMATION SYSTEMS RESEARCH NEEDS:

THE FEDERAL AGENCY VIEW

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PLENARY SESSION 1

GEOGRAPHIC INFORMATION SYSTEMS RESEARCH NEEDS: THE FEDERAL AGENCY VIEW

CHAIR: Robert Lee Chartrand, Congressional Research Service

PANEL: Ronald F. Abler, National Science Foundation
Paul Huray, Office of Science and Technology

Research Needs in Geographic Information Systems: The Federal Agency Perspective. Ronald Abler:

My task this morning is to review the federal agency perspective on geographic information system research needs. I have been greatly assisted in conducting that review by short statements prepared by the Bureau of Land Management, the Bureau of the Census, the Defense Mapping Agency, the Engineering Topographic Laboratories, the Environmental Protection Agency, the Federal Emergency Management Agency, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the U.S. Forest Service, and the United States Geological Survey. I have also consulted a survey of GIS activities in federal agencies that was conducted early this year by the Federal Interagency Coordinating Committee on Digital Cartography (FICCDC).

My comments on relationships between the federal research agenda on the one hand and academic research priorities on the other rely on the consultation process that produced the research agenda proposed for the National Science Foundation's National Center for Geographic Information and Analysis (NCGIA). I shall also refer to material presented at a September conference on GIS research needs held in Edinburgh under the auspices of the National Science Foundation (NSF) and one of its counterpart agencies in Great Britain, the Environmental and Social Research Council (ESRC).

Agency Research Needs

I shall not catalog in detail the research needs of each agency that prepared one of the statements I have consulted. Each agency has a representative on this panel. Each of them will have a few minutes to speak to his or her agency's specific needs. I believe my time will be most profitably spent highlighting what is <u>common</u> among agency needs, using specific examples as appropriate. I will then assess those commonalities and needs by comparing agency needs with academic needs and by placing both in a broader context.

Data-Related Needs

One thing that comes through clearly in the statements I

consulted is that data-related needs are still a high priority for most agencies. They revolve particularly around the extremely large and complicated databases many agencies are charged with collecting and managing. Other data-related needs are related to the necessity to use and rely upon spatial data collected by other agencies and organizations.

Large data sets. Hardware and software that are more hospitable to large data bases are needed by a number of the surveyed agencies, especially Census, Defense Mapping Agency, NASA, and USGS. The data volumes those agencies must store and manipulate in coming years are staggering. Census's TIGER File and the USGS's National Digital Cartographic Data Base will be data sets of unprecedented size and complexity. NASA is now building satellites that will capture data faster than any current technology can record and store it. Advances in both computer architecture and data structures are, therefore, prerequisite to the widespread use of GISs in accomplishing agency missions, especially if there is to be any hope of using such data resources interactively.

Standardization. Among the research needs identified by the ten agencies noted above, standardization and exchange standards appeared frequently. It seems eminently sensible to ensure that data created by one agency are captured in a form that makes them usable by other agencies. Achieving that common-sense goal will not be easy. I suspect many agencies' views of standardization could be summed up by the old expression, "Be reasonable! Do it my way."

The benefits of standardization are future potentials; the costs of standardization are immediate. Gathering data someone else's way will always be less convenient that doing it your own way. I foresee continued difficulties in agreeing upon exchange standards and continued resistance to standardization despite the large number of agencies that mentioned it as a research priority.

Flexibility and Conversion

A number of specific research needs are tied to a widespread desire to overcome the constraints imposed by data formats, by hardware, and by incompatible software. Many agencies keenly feel the need for a GIS equivalent of Esperanto.

Flexibility and Integration. Flexibility and integration needs focus on tasks such as integrating data for ecological analyses and decision making (a need cited by the Forest Service). Data fusion was identified as important by the Defense Mapping Agency, which seeks a single data structure for many kinds of information, from raw facts and numbers through intermediate products to hard copy and video-display outputs. Software that will accommodate user-specified data densities would also be helpful. FEMA needs to change scale rapidly, to go from very

large scales to very small scales so as to see a detailed local picture and then place those details in a regional context. Doing so requires techniques that do not exist for shifting from one data density to another. Integrating processed digital imagery with other kinds of data--for example, integrating raster topography with a vector coastline, or in the case of a NOAA need, satellite weather data (raster) with ground-based vector information--is a continuing and persistent problem that concerns a number of agencies. Achieving greater independence of hardware through improved software would please many agencies, for most GISs remain device-dependent.

Conversion. Conversion remains a significant problem for a number of agencies. Great savings would result from improvements in methods for converting hard copy maps and other kinds of information to digital form, especially for DMA and USGS, two agencies responsible for producing large quantities of maps in digital form as quickly as possible. Artificial intelligence and expert systems that would assist the process of converting analog to digital data and reduce human time required for such tasks were often mentioned.

Scale. Scale transformations and their attendant problems concern several agencies. I've already mentioned FEMA's need to look at small areas in great detail and then step back to see the broader context of an emergency such as a chemical spill. Crisis managers need great detail about the area immediately surrounding an emergency and good regional context for purposes of planning evacuations and marshalling assistance. The Defense Mapping Agency has similar needs to move across a variety of observation scales quickly and efficiently. At what is perhaps the other end of the scale, NASA and NOAA are responsible for developing data systems of global scope, which presents its own set of data management and transformation problems. Relationships among data density, data storage and management, scale of analysis, scale of presentation, and scale transformations will be persistent research needs for several agencies for the foreseeable future.

GIS Use Issues

There are a variety of agency concerns related to what different actors will actually do with geographic information systems.

Modeling. Data cannot be transformed into information until appropriate models are available to structure them. Computer processing methods for manipulating massive amounts of data in the search for relationships and dependencies among geographical units and locations would enhance the operations of several agencies. Knowledge-based inference models and routines for modeling cartographic objects and entities are high priorities at the Geological Survey. NOAA is particularly interested in query capabilities, pattern detection, scenario generation, and cost-benefit methodologies. The Forest Service values techniques for

modeling fire outbreaks and spread under varying climatic and topographic conditions, and GIS-based models of insect infestation and diffusion. Most modeling needs noted by agencies were two-dimensional in nature, but USGS and NOAA are interested in three-dimensional data structures and display capabilities, and in systems that can easily accommodate time-dependent data.

Human-machine Interfaces. How people relate to GIS hardware and software is of particular concern to agencies with operational responsibilities such as the ETL, FEMA, NASA, and NOAA. When spatial information is to be used for making critical decisions in real time, considerations of what data are relevant, and of how only relevant information can be presented concisely and effectively become paramount. FEMA is now proceeding with the installation of its Integrated Emergency Management Information System (IEMIS), an interactive GIS that provides a suite of capabilities that can be accessed in parallel by many networked users. ETL is developing similar capabilities for battlefield applications in its Digital Topographic Support System (DTSS).

Security. Security is an obvious concern for organizations such as DMA and ETL, but their needs have broader implications. An increasing number of databases consist of mixtures of confidential data and information that should be accessible to potential users. Data collected by the Census are an example of such a mixed compilation. There exists a real need for techniques that will enable users to access government databases while protecting confidential data, such as those covered by Census disclosure rules. Security is an emerging GIS research frontier, in which civilian applications may benefit greatly from work conducted by defense-related agencies.

Federal Agency Needs in Context

Let me place federal agency needs in context by comparing them with the GIS needs identified by the academic research community.

Research at the NCGIA

The center's research agenda will be determined by the comparative strengths of the winning institution, but it seems likely that the center's agenda will address:

1) Advances in spatial statistics and methods of spatial analysis, an item that did not appear on the list of research needs prepared by federal agencies.
2) A general theory of spatial relationships, another desideratum of the academic community but not of government.
3) Artificial intelligence and expert systems in GISs, which did figure prominently in the agency lists of needs.
4) Database structures, the problem mentioned most often by government agencies.
5) Visualization is a topic that was not mentioned by name

on agency agendas. It is, however, implicit in the concerns about human/machine interfaces noted by a number of agencies.

6) Social, economic, and institutional impediments to GIS use were not deemed to be problems by the agencies, but they are of concern to the academic community; as Terry Coppock has noted, theoretical and technical advances are necessary conditions for the wider adoption of GIS, but they are not sufficient conditions. Government agency adoption of GISs is susceptible to top-down direction, conditions which are often absent in non-federal and non-government applications.

NSF/ESRC. I referred earlier to a joint NSF-ESRC conference held in Edinburgh in September 1988. I would like to highlight the differences between agency research agenda and the priorities identified at that conference.

In the realm of data, the major difference that separates government practitioners from academics is the concern among academics for geographic information systems that will accommodate movements of objects from one place to another. Whereas federal agency needs are primarily for static views, university scientists desire modeling capabilities which incorporate flows and change.

The academic community places more stress on query capabilities than do most federal agencies. The majority of federal GIS products are specified by planners or users in advance of need, and mutual interaction between user and system was not cited as an important consideration. Exceptions are FEMA's interactive network described above and the Bureau of Land Management's Interactive Automated Land and Mineral Record System.

While by no means absent from the federal agency agenda, modeling is of considerably greater concern to the academic community than it is to many federal agencies. The university community sees a large gap between the capabilities of current geographic information systems and the kinds of spatial analysis that could be developed on the basis of flexible geographic information systems applied to real social and environmental problems. Whereas many in the agencies view GISs as a technology for storing, manipulating, and presenting geographic data, academics view the technology as a tool that will enhance modeling capabilities for purposes of developing spatial analytic theory as well as in support of decision making and planning.

The integration of remote-sensing, GISs, and cartography into a single, unified information system for the capture, storage, manipulation, and display of spatial information figures in the academic agenda but was noted only indirectly in agency agendas. The research community currently regards those three pieces as separable, as distinct technologies and research foci. In the long run, they will be integrated into a single

information processing technology, and all parties should be moving in that direction. NASA has been supporting work along such lines, and EPA is conducting research at its Las Vegas Environmental Monitoring System Laboratory leading in the direction of integration.

Aside from NASA, there was little explicit consideration among federal agencies of the need for international work in GISs. It will eventually be necessary to integrate national databases and grids into a global locational and data base system. The sooner that work is taken in hand by all parties, the less difficult will be that inevitable merging.

The most important and striking difference between the government and the university GIS communities is the concern of academics with accuracy, a topic which was scarcely mentioned in the agency lists. It is critical to know whether the maps that can easily be created on GIS video screens are sound foundations for inference and decisions. As Michael Goodchild has noted on numerous occasions, statistics for spatial data are one of the GIS community's most pressing research needs. We have no confidence limits for the measures we can create with geographic information systems. We know little about how error propagates through geographic information systems when maps are combined and permuted and when scales are changed. If a GIS is to be a useful tool, we must determine how much faith we can place in its products.

Overview

These are exciting times. GIS fever is abroad in the land. There have been more meetings devoted to GIS in the last year than I have been able to track. What is especially exciting is that the agendas among federal agencies with GIS responsibilities, the research needs of the academic community, and the programs of the private sector--which I've not heretofore mentioned--are similar in many respects and complementary where they differ. We use different words in some instances, but a large number of basic concepts and common problems underlie our respective efforts.

Funding for research to address our common and respective needs is not what it should be, but that situation is improving. Most agency expenditures are allocated to operations, but serious amounts are being devoted to research, especially by the Department of Agriculture, at $1.6 million in Fiscal Year 1988 and by the Geological Survey at $2.0 million. The National Center for Geographic Information and Analysis will have a research budget of $1.25 million per year for eight years. That will be as much as has ever been available for GIS research over an extended period of time in non-defense applications. We at the Foundation view that amount as a nucleus that should attract additional funds to NCGIA from other sources.

If increased funding is one reason for optimism about progress in GIS, another is the emergence of institutional structures that will promote collaboration on items that are common to government, private, and academic research agendas. Most of the agencies that prepared the statements upon which my comments are based have cooperative programs with other federal agencies and with the university community. To realize maximum benefits from GISs we need to think creatively about new institutional structures that will draw the private sector into more active collaboration with government and the academy. I suspect that the cutting edge of research in GISs is likely to move from universities and government agencies to the private sector in short order. To maintain currency, government agencies and universities will have to be receptive to unorthodox and innovative collaboration, and I hope that the NCGIA will be a mechanism for fostering multi-sector collaborative research on GISs.

I judge this conference to be a promising means for realizing some of the goals I have identified above, whether they are needs shared by the various players or whether they are needs that are primarily the province of one of the respective GIS research communities. To be sure, there are differences among the government, the private, and the academic communities. But I am more impressed with our common aspirations and complementary perspectives than I am with the differences in emphasis or priority that I have noted. Opportunities to compare and contrast those perspectives and priorities, such as those afforded by this conference, will promote progress toward achieving our mutual aspirations in GISs and GIS use.

Policy Perspective. **Paul Huray:**

Last week, I had the pleasure of having lunch with a Nobel prize winner who works for one of the major corporations in America. He was telling me what life was like in his company. I'd always assumed that a Nobel prize winner did whatever he wanted to do. I was really taken aback when he began to describe to me a typical day for him. It turns out that these days he has to fill out time cards. For someone in academia, of course, that's quite foreign. He was telling me that not only did he have to fill out a time card, but each hour of the day he had to describe which product line of that corporation he was working on. In fact, if he went to a seminar, he had to describe which product line that seminar best applied to. I'm sorry to say that it's not an exception these days. It's becoming the norm in corporations of America. It's a characteristic of American industry that we in the White House have been concerned about. We think that the corporations of America are becoming shorter sighted than they should. We can't, of course, be too critical about that kind of response because stockholders, who have absolutely no loyalty to a corporation, shift their funds from one category to another, sometimes with a computer, not even

knowing what they're doing. And it's next quarter profits, of course, that determine just how their funds are transferred. So shortsightedness is a characteristic that's driven by external causes. We don't think it's healthy. And we've been looking for an appropriate response for some time.

Last year about this time, there was an article in the Chronicle of Higher Education--perhaps you saw this issue. It had as its headline, "White House Pushing Campus Centers for Interdisciplinary Science Research." It's no accident that up in the left-hand corner just above the headline, it said, "Boosting U.S. Competitiveness." That's what I want to talk about this morning in relation to the Geographic Information System Center that will be established in the NSF.

A little later in the year, the following headline was published in Business Week. "At Last. A Reagan Technology Policy?" We didn't like the fact that it was implying that there hadn't been one before, and we especially didn't like the question mark at the end of the sentence. Nevertheless, in the last year there have been a number of discussions going on here in Washington about how federally funded science and technology could be adjusted to better complement the way in which business was carrying out its research and development. I'm going to talk a few minutes this morning about the environment and some trends which have led to this new policy.

The first trend involves the numbers of scientists and engineers who are engaged in research and development per 10,000 labor force, that is, normalized for different countries to reflect their different population size. In 1966, there were 67 scientists for every 10,000 people in the labor force in the United States. Up to the middle 1980s the United States population of scientists and engineers has remained relatively constant. By comparison, Japan, West Germany, and France started far lower than us in 1966 (25 per 10,000 in the labor force), but they've been increasing the number of scientists and engineers steadily over that same period. In fact, they're catching up with us. For the Soviet Union it's a little hard to evaluate, but it's estimated that they're considerably ahead of us with as many as 100 per 10,000 in the labor force. We believe these trends are having a tremendous impact on our balance of trade.

The U.S. balance of trade is of very much concern here in Washington. It's almost all that's been talked about over the last year or so. If you examine a time plot from 1970 through the mid-1980s of our overall balance of trade with other countries, you will see that it fluctuates between negative $5 billion per year and negative $20 billion per year for the seventies and that it's going more negative for the eighties. However, if you examine our balance of trade in high technology components, you will see that it's positive over most of that period, fluctuating between positive $5 billion and positive $15 billion. In other words, the balance of trade in high technology

has been holding up the overall balance of trade for the United States. It's a little discouraging, however, to look over at the high technology component, toward the mid-1980s. In 1984 the U.S. trade position in high technology alone was positive $27 billion per year. By 1986 the balance of trade in high technology products had become negative $3 billion per year. This spells bad news for the overall balance of trade because this has been one of the very few positive components over the past two decades.

It's the Administration's science policy that the federal government has the responsibility for long-term high-risk research, and that basic research can best be done in our universities and our federal laboratories. What's disturbing us is that while the federal government has been funding more basic research in our universities; in our industries, as I described by my little example at first, there's been more shortsighted investment going on. Most of the funding increase in corporation R&D has been occurring in development, getting investment closer to the product line, and not as much in basic research. We have two trends diverging!

In order to make my point clearly, let's examine federal government research and development obligations over the last decade. I will ignore defense spending because defense is the 300-pound canary. I don't want to add the $45 billion in defense spending for research, development, testing, and evaluation because it would greatly skew the trend, and defense spending is not driven by the same policies as non-defense spending. Federal policy for non-defense spending eventually translates itself into dollars so we should examine development, applied research, and basic research funding levels separately in constant dollars, that is, with inflation removed. In constant 1985 dollars, federal funding for development--synfuels, windmills, breeder reactors--has fallen consistently since 1979 from a level of $8.7 billion to a level of approximately $3.5 billion today. By comparison, federal funds for applied research have been approximately constant over that period at a level of $6 billion to $7 billion per year. And the federal investment in basic research has been increasing in real terms significantly, from $5.3 billion in 1979 to $9.0 billion in 1988 (about a 70 percent increase over the last decade in real dollars). Thus, there are definitely two trends diverging because if we look at the comparable figures for industry R&D, we will find basic research and applied research holding relatively constant at $2 billion and $10 billion per year today (in constant 1985 dollars).

This Administration, and previous ones, have felt there are three important things the federal government should be doing: (1) It should be generating new knowledge through basic research; (2) It should be expanding the talent base through additional graduate students, primarily in universities; and (3) it should be transferring technology to industry--that's what my primary message is about this morning.

Last year, the President in his State of the Union address announced a new initiative, Science and Technology Centers, and in the same paragraph, he talked about the fact that the National Science Foundation budget was going to be doubled over the next five years. Believe me, those two things had a lot to do with one another. The fact that American industry was becoming shortsighted and our balance of trade was headed negative compared to other nations coupled with the fact that our basic research funding was increasing in the federal government was pushing us toward two separate cultures. The Economic Policy Council (EPC) decided it would be wise to continue to invest in federal funding of basic research but to emphasize science and technology centers. The EPC didn't want to disrupt the great strength of American science and technology. Thus, they recommended a perturbation of incremental funding. This funding is not scheduled to go beyond about 10 percent of university funding and that would only happen after a long time. The President's scheduled plan for the NSF budget was delivered to the Congress in February. The current NSF budget is $1.6 billion dollars, and there are 14 existing science and technology centers. Actually, they're engineering research centers, but we say those are in the category of science and technology centers because they fund activities in which business and universities are beginning to work together to provide technology transfer through people: graduate students, faculty, industrial researchers on campus.

Now let's look at the NSF funding projections. Up to 1988 and beyond through 1992, the President has made a request to increase the NSF budget first this year by 17 percent, to $1.88 billion, and eventually up to $3.2 billion, doubling the NSF budget. In parallel with that funding increase, science and technology centers are proposed to increase by an amount that's not completely specified, but perhaps to 70 to 80 centers. One of those centers, at least, will be in Geographic Information Systems. I've given you this background because I think it's important to understand the environment in which these centers were generated. The history tells you something about the way in which we would hope that the science and technology centers would operate eventually, and the GIS center in particular.

As you know, there is some discussion on Capitol Hill and in the White House about a compromise, and unfortunately, one of the easy targets for compromise is in science and technology funding. The House has recommended almost the full increase the President asked for. Of course, this was back in the summer time. The President asked for $1.88 billion; the House recommended $1.79 billion. The Senate was even better than that; it recommended $1.87 billion for the NSF. In other words, Representatives and Senators of both political parties agree to this philosophy of putting funds into activities that lead to economic competitiveness.

Now since Bob Chartrand works in the Congressional Research Service, we thought it would be appropriate for him to give you a perspective about how the House and Senate are likely to react to this proposal in an environment of budget compromise. So I'm going to stop here and let Bob take over to tell you what's going to happen this week.

Policy Perspective. **Robert Chartrand:**

I think anyone that would stand here before you on a Monday morning with all innocence and say that he was clairvoyant about the House and Senate would be a brave person indeed. If spending 21 years on the Hill is of some aid--and sometimes I think it is and sometimes I think it isn't--then there are things to be learned! One of the things that comes to my mind when being with a group like yours, and I have had the pleasure of working with many of your agencies over the years, is that you have a really unique responsibility. You may not like that responsibility, but it's there, and it's something that needs to be mentioned. And that is if Congress is going to be responsive to the needs of the nation in science and technology--and both Paul and Ron have done an able and very fine job of presenting useful views as they should be understood today including those from the agencies and most certainly the Office of the President--then I believe that your responsibility is to make sure that the people on the Hill are educated and properly "oriented" so that they really understand what these programs are.

You know, time and again I have had individuals from agencies come to me <u>sub rosa</u> and say, "How do we present our program to the key Members and the staff people on Capitol Hill so that they will be understanding and responsive and so that we get a 'fair shake' in terms of our plea for support in the authorization and appropriations processes?" I cannot offer anything of greater criticality to this group than that there must be helpful preparation for these people who have great demands on their time, who for the most part do not have a background such as yours in what we could loosely call "science and technology," and who need and want that sort of understanding so that they can look at the options. It's very, very easy when you are close to a subject and are professional in an area to stand back and say, "Why, of course! There are four obvious options/actions--one, two, three, four. Why can't those idiots up there understand that?" Because for the most part, no one ever goes there except to give formal testimony, and, my friends, if you think that that is the best time for us as agency people to present our case to the Congress, you are wrong. There has to be that <u>extra effort</u> made, and a <u>continuing effort</u>, so that they really can come to understand.

For the past six or seven years, I have been working intensively, as some of you know, in the field of "emergency management." A particular focus has been on the role of

information technology in emergency management. This is not something that the Members of Congress and their staff people are attuned to. There are a few, of course, that really understand when you talk about this. They may have a particular background. There may be someone like Senator Don Riegle from Michigan who worked for IBM or an individual, such as Senator Al Gore of Tennessee, who is probably the most knowledgeable person in the field. But to take it for granted that these few isolated pockets of understanding are going to "carry the day" for us, when it comes to our programs, is being naive and would be overestimating the situation.

What it comes down to, then, is that we have to understand what has been done already in terms of the creation of public laws that affect us in our work, and secondly, what new legislation is before the 100th Congress today in areas that affect us, whether it is in research and development per se (and we've heard a great deal about that this morning) or in terms of ongoing operational programs.

I took the liberty this morning of bringing along two separate handouts. And this is not because any of you needed "bedtime reading"--although I'm sure that for insomnia, this is an absolutely superb antidote--but the first of these offers, if you'll spend a few moments looking at it, an overview of the more than 280 public laws that have been passed in the last decade. Now listen to what I'm saying! Two hundred and eighty public laws have been instituted which affect all of us in the general field of information policy and technology, and that's only in the last ten years. It's incredible! I have said to other audiences that if we all sat down with a piece of paper and someone said to you, "We're going to have a little examination" --and by the way, I'm out there with you doing this--"How many public laws in this realm could you list, just off the top of your head, that influence directly what we do?" I would be lucky to come up with 10 or 15. And yet there are more than 280 of these things out there floating around! Sometimes the Congress, usually with strong urging from the citizenry and special interest groups, takes action to pass a piece of legislation that creates a clearinghouse information service or an R&D program or what have you. It behooves us as professionals in the field to have at least some glimmer of what these things are that affect our daily lives and the operation of our agencies. I'm not trying to get too heavy here, but I think this is important that we try to do this.

The second handout takes a look at about 125 of the bills and resolutions introduced in this Congress. They have not passed yet, so I'm differentiating because many are ones that will be receiving action in the House and Senate. People tend to be critical of Congress and may ask why in today's world, members can't find a consensus? What is it that should be done? It's very difficult! I would say that compared to when I first came to the Hill, the difficulty in finding a consensus, a working

solution, is many, many magnitudes more difficult than it was 20 years ago, in most cases because there are so many pressures being exerted.

Somebody commented one time--and this is in a little bit different context but I think it bears telling--that when Calvin Coolidge was President someone was commenting on his performance in that office. That someone was Will Rogers, a person from whom we could still learn a great deal. And he said, "That gentleman's performance is just like a ukulele player. You couldn't tell if he was serious or just messing around!" Sometimes people view Congress that way. But sincere efforts are being made there. I think it's very important that we understand this.

We have been looking here at some special "geographic information systems," and I'm proud to say that I've been working off and on, in and around such facilities and activities since my early days as a photo interpreter and photogrammetrist when we relied tremendously on less sophisticated geographic information systems. I was also thinking, when we were talking earlier about keeping track of the hours on projects, Paul, that we were doing exactly that at TRW in 1959 when I worked there. And we weren't any happier about it then than they are now. If anyone believes that's a new phenomenon, go out and "take a walk" and come back in again. We were doing it then on exactly that same hourly basis, and everybody hated it. Some of these bad traditions have been around with us for a long, long time!

So, the ability of people on the Hill to understand what you are doing--and I'm coming back to my initial theme--that requires their being told more than once, and in an understandable way. Sometimes this can be done through seminars, sometimes through other programs.

My final comments are to simply say that this is a most important meeting that we're engaged in. It is scarcely the first, of course. We have already heard references to many other things that have happened recently in terms of focal efforts in your field. The many changes that are occurring in these tumultuous years brought to mind a quotation from a gentleman who was indeed unusual. I refer to Thomas Jefferson. I would like to end my part of the plenary presentation by quoting this maxim of his which should be chiseled in stone and placed in the back of the room so that we could all reflect upon it. "Laws and institutions must go hand in hand with the progress of the human mind. As that becomes more developed, more enlightened, as new discoveries are made, new truths disclosed, and matters and opinions change with the change of circumstances, institutions must advance and keep pace with the times."

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DEFENSE MAPPING AGENCY
Mission Statement

The Defense Mapping Agency (DMA) mission is to provide Mapping, Charting, and Geodetic (MC&G) support and services to the Secretary of Defense, the Joint Chiefs of Staff, the Military Departments and other DoD components through the production and worldwide distribution of maps, charts, precise positioning data, and digital data for strategic and tactical military operations and weapons system. DMA serves as Program Manager and coordinator of all DoD MC&G resources and activities. DMA provides training for the Military Departments and other DoD Components. DMA also carries out statutory responsibilities for providing nautical charts and marine navigation data for the use of all vessels of the United States and of navigators generally. To support its mission, DMA employs more than 9,000 professionals at 50 locations throughout the world.

DMA currently maintains both hardcopy and digital data bases consisting of topographic and hydrographic information as well as representations of the earth's gravity and magnetic fields. The information contained in these data bases is used to support the generation of printed maps and charts and digital products. These products, in addition to being hardcopy or digital, exist at varying scales and in differing security environments. DMA's research needs in the GIS and data base management arena derive from the conversion of these existing data bases to an all-digital environment, and the requirement that a single data set support interoperability in addition to the generation of single or multiple products.

Given the stated requirements, DMA is faced with a unique set of GIS and data base research interests. The underlying digital data and data structure must be robust enough to support the generation of digital and hardcopy products and flexible enough to accommodate the linkage of ancillary materials (text and graphics) to the spatial data which these materials support. The management of these data must account for security differences between linked data files and elements, and provide security controls for access to these data. Finally, the volume of these data necessitates the use of extremely flexible and efficient storage and retrieval methods.

DMA has undertaken a series of initiatives which address some of these research areas. The issue of spatial data handling for hardcopy and digital product generation has been addressed through the ongoing development of a spatial, topologically based data structure. Work still needs to be done in the area of data fusion, to provide a single data structure which would integrate the softcopy, symbolized renditions of "raw" spatial data in the data base, ancillary materials and the original spatial data. Data fusion, for intersecting various elements of spatial data to arrive at a new set of spatial data in response to a query, needs to become much more sophisticated. As the demand for such

sophistication grows in response to client requirements, the underlying data structure and content must also necessarily become more robust. Additional work will be needed on the effect of sophisticated fusion techniques on the supporting data elements and structures.

Overlayed on the above research is the issue of multilevel security, and the behavior of spatial data when large volumes are being manipulated. Extensive R&D will be required in the area of very large spatial data base storage and retrieval techniques. Relatively little is known about enhancing the performance of extremely large data bases in the areas of concurrency of access, storage media, and fusion.

In summary then, DMA GIS and data management needs necessitate that any solution account for the data requirements of product generation, the association of ancillary and spatial data, and the efficient storage and retrieval of these data in raw, processed, or combined form. These same research areas must also address associated security constraints. These are the areas which DMA believes need further investigation.

BUREAU OF LAND MANAGEMENT
Mission Statement

The Bureau of Land Management (BLM) is responsible for the balanced management of the public lands and resources and their various values so that they are considered in a combination that will best serve the needs of the American people. Management is based upon the principles of multiple-use and sustained yield, a combination of uses that takes into account the long-term needs of future generations for renewable and non-renewable resources. These resources include recreation, range, timber, minerals, watershed, fish and wildlife, wilderness and natural, scenic, scientific and cultural values.

The BLM's stategy is to manage current and developing geographic information technology in order to use data assets more effectively for the management of Public Lands and resources. The framework for this strategy is the implementation of an operational automated Land Information System in the early 1990s. The Land Information System will have the following components:

(1) An automated Geographic Coordinate Data Base using inputs from the National Public Land Survey System (PLSS) which is operated by BLM.

(2) An Automated Land and Mineral Record System (ALMRS) built upon the National Public Land records system operated by BLM to provide information for legal land ownership, land status and use information in support of Federal programs and public users of the records.

(3) An automated natural resources data which depicts the resource values, use conflicts and characteristics of the public land and mineral resources managed by BLM.

The Bureau of Land Management does little pure research. Rather, the Bureau's research and development efforts mix and adapt new technologies to Bureau's needs. In the Bureau, the field organization is the source of ideas. The BLM analyzes these ideas and needs to formulate a program of development and research. By necessity, the Bureau's development and research system has multiple objectives and serves clients at all organizational levels. It is, therefore, a decentralized system. The strength lies in the fact that it is responsive to needs for all Bureau programs and at all management levels. It also accommodates fresh thinking.

The Bureau's Denver Service Center has a mixture of resource and administrative people that are addressing ongoing Bureau operations with purposeful searches for improvements that will carry the Bureau of Land Management into the year 2000 and beyond.

FEDERAL EMERGENCY MANAGEMENT AGENCY
Mission Statement

Under direction of the President, the mission of the Federal Emergency Management Agency (FEMA) is to plan for and coordinate the protection of the civilian population and resources of the Nation, to include planning for the continuity of constitutional government in time of emergency.

To accomplish its mission, FEMA acts as the focal point for all levels of government in developing a national emergency mangement capability that can deal effectively with any major emergency.

Toward the creation of this capability, FEMA develops and coordinates programs and activities to prepare for, mitigate, respond to, and recover from natural, technological and attack-caused civil emergencies; develops program guidance and plans to assist government at all levels in planning to cope with and recover from emergencies; supports State and local governments in disaster and emergency planning, preparedness, mitigation, response and recovery efforts; coordinates Federal assistance for Presidentially declared disasters and emergencies; develops programs for population protection including warning, shelter, and evacuation planning, and for emergency information; administers the United States Fire Administration, the Federal Crime Insurance and the National Flood Insurance programs aimed at reducing the Nation's loss of life and property in these areas; and develops and provides training and education for Federal, State, and local fire service personnel and emergency managers to enhance the preparedness and professional development of all levels of government.

Each of the FEMA mission items has a single element in common: the need for spacially related data organized for use by a multiplicity of organizations at every level of government.

Research and development sponsored by FEMA in this area has concentrated on a world class software system which could be operated on a large network of independent, stand-alone workstations, but which could be connected with a national, distributed data processing system. As part of FEMA's Integrated Emergency Management System policy, FEMA is attempting to develop, test, and guide general implementation of this software system using the multiple user approach on a host of everyday applications involving civil emergencies. In the ultimate, such a survivable, distributed data processing system, if implemented nationally, could be invaluable in times of major civil crisis.

This software system is called the Integrated Emergency Management Information System (IEMIS). The key element of interest to this presentation is the interactive geographic system (GIS) which underlies the entire suite of activities, and which is designed for parallel participation by a very large

number of users in a networked mode.

A key operational concept which guides the FEMA R&D effort is the assembly of thematic site maps from a combination of digital sources, and integrating this information with a single point and line system using longitude and latitude as a universal locator. With this concept, scale in maps disappears, and the accuracy of point data becomes the limiting factor. Thus, within a single software system, a metropolitan government can define utility service line locations to inches while retaining capability to operate at the macroscopic level. Simultaneously, Federal and State agencies can assemble thematic data bases for planning and event mitigation at the regional level.

In the light of this requirement, the specific research goals of vital interest to FEMA include:

(1) defining software systems which are flexible enough to respond to user despecified data densities in order to meet individual accuracy or file size and access time limitations;

(2) dealing with the networking of existing computers and data bases to permit building of a transferable, mutually usable, national data system;

(3) continuing study of the practical limits of data standards development in order to create flexibility within the widely varying community of users;

(4) studying the day-to-day system use in practical situations in order to test research goals and guide development targeting; (To this end, FEMA actively cooperates with Federal, State, and local organizations in establishing local nodes for data assembly and networking.)

(5) developing information which allows installation of the most practical state of-the-art algorithms for modeling and data integration; and

(6) continuing study of high density storage devices with low seek times and high reliability which can be used in a national, distributed system.

To this end, FEMA is stimulating installation of IEMIS in universities which are interested in working with State and local officials on integrated systems. Through the Radiological Emergency Preparedness program, a number of jurisdictions are installing IEMIS as a part of joint operations with the utilities for the purpose of studying local use in an R&D context, while performing official functions such as evacuation time estimates.

In addition, FEMA is cooperating with Federal agencies which are implementing IEMIS as part of their programs. These are

principally the Department of Defense and NASA. Work performed by contractors of these Agencies is expected to address current FEMA research objectives which include inclusion of non-uniform raster grids, non-uniform user-defined arc-node constructs and integration of raster/vector data files with a relational data base management system such as INGRES.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Mission Statement

The National Aeronautics and Space Administration (NASA) was established by the National Aeronautics and Space Act of 1958. This legislation was enacted to provide for research into the problems of within and outside the earth's atmosphere, and for other purposes. The objectives of the NASA program of research and development are to expand our knowledge of the Earth, its space environment, and the universe; to expand the technology for practical applications of space technology; to develop and improve manned and unmanned space vehicles; and to assure continued development of the long-term aeronautics and space research and technology necessary to accomplish national goals.

Within NASA, personnel and programs of the Office of Space Science and Applications (OSSA) further these objectives through a program using space systems, supported by ground-based and airborne observations. These objectives are (1) to conduct a broad spectrum of scientific investigations to advance our knowledge of the Earth and its space environment, the Sun, the planets, interplanetary and interstellar space, the stars of our galaxy and the universe; and (2) to identify and develop the technology for the useful applications of space techniques in the areas of advanced communications satellite systems technology, materials processing research and experimentation, and remote sensing to acquire information which will assist in the solution of earth resources and environmental problems.

The primary overall goal of the Earth Science and Applications Division (ESAD) is the investigation of the Earth as a system from its interior through the mesospheric/thermospheric boundary. Traditionally, the Earth science disciplines have advanced through individual component studies, e.g., interior, crust biosphere, oceans and ice cover, atmosphere and ionosphere. Recent research, however, has made it clear that land, atmospheric, oceanic and biospheric processes are strongly coupled. To understand our environment and ultimately to predict global change induced either naturally or through human interaction, it is important to study the Earth as a single coupled system as well as to answer questions arising in such separate disciplines as atmospheric chemistry, climatology, biology, ecology, geology, geography, meteorology, and oceanography.

As such, ESAD is critically interested in Geographic Information Systems (GISs) from both an analytic and a data management perspective. NASA space and aircraft systems have the ability to acquire large volumes of data in both digital and analog formats. We need to improve our ability to integrate these data into data/information systems wherein a component is a GIS. These data combined with other more traditional data can then be used to inventory, map, monitor, and model key components of the global system. The key is to integrate these data so that

they may be manipulated, integrated, and processed in such a fashion as to improve our fundamental understanding of the rates, directions, and magnitudes of environmental processes and changes.

To achieve a capability where such research is truly feasible, we feel that research is required in a variety of areas of GIS technology from improved data structures to better spatial data base management systems, from improved man/machine interfaces through the more efficient integration of processed digital imagery.

To the extent that such GIS research directly supports the science and applications needs of the NASA Earth Science and Applications community, we are interested.

A recent report of the Earth System Sciences Committee entitled "Earth System Science: A program for Global Change" states:

> "Of paramount importance to the success of Earth System Science is an advanced information system that will promote the productive use of global data. The worldwide space and in situ observation required for a deep understanding of the Earth System can be utilized only if the research community has effective access to them. The design, development, and management of the requisite information system are tasks that approach in scope and complexity, the design, development and operation of space-based observing systems themselves."

The problems are real and needs are there.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Mission Statement

The National Oceanic and Atmospheric Administration (NOAA) was established October 3, 1970, in the U.S. Department of Commerce. NOAA was formed to monitor and predict conditions in the atmosphere, ocean, and space, explore the feasibility and consequences of environmental modification, and provide information for rational and effective use of ocean resources.

Given NOAA's mission, the need for georeferenced data systems has existed since NOAA's formation. In the 1970's with the advent of readily available computer resources, NOAA began to develop many unique computer programs that combined scientific data sets in a limited variety of ways for specific applications. These systems have evolved in sophistication and efficiency over the years, and many are still in use today (for example, Hittelman and Metzger, 1983). With the great improvement of GISs over the last three years, line offices in NOAA have started to realize the great potential of these systems for marine resource monitoring and global change detection.

In the National Environmental Satellite, Data, and Information Service, the Assessment and Information Services Center (AISC) routinely uses scientific data and models for diagnostic and prognostic marine impact analyses. These GISs can support state environmental managers that have to deal with: the constantly changing dynamics of the marine environment, the mobility of the fishery resource, the shortage of data, and oversimplification of existing biologic and circulation models.

The system used by AISC is a micro-based software package tailored for coastal applications. It duplicates almost all of the applicable functions of larger, more expensive mini- and super micro-based systems at a fraction of the cost. It consists of a control monitor with menu access through a keyboard, a high resolution color display monitor, software for a GIS, image processing, and professional graphics.

The National Geophysical Data Center incorporates the Map Overlay and Statistical System (MOSS) in both an operational and research mode. NGDC currently is using a GIS to support the Environmental Research Laboratory's study of alkaline dust emissions in the support of the National Acid Precipitation Assessment Program. Each of the USDA's Soil Conservation Service Major Land Resource Areas is evaluated by NGDC scientists for various environmental loading factors such as dust emission, calcium composition, etc. NGDC is also working to combine and enhance the new generation of public domain GIS packages into a GIS superstructure for its future needs. Research at NGDC includes using GISs and DBMS for global inventories and applications of geophysical data.

The research needed in GISs to support NOAA's requirements is described below:

Global Capabilities. Most present GIS applications are used in very small geographic area applications such as a county or a 7 1/2' quad. Since the historical uses of GISs are for these areas, global applications are sometimes difficult. One reason for this is that the amount of data required to represent a global parameter at high resolution may use all of the available CPU resources, RAM memory or disk storage; and to perform a meaningful GIS analysis, many global parameters are needed. Other problems are more mundane such as projections (e.g., only a Universal Transverse Mercator using S,Y, coordinates may be available in some systems when a regional or global projection such as a Van der Griten, polar stereographic or Lambert Conformal Conic is needed). In addition, some GISs cannot smoothly handle data sets that span the International Date Line or the Prime Meridian.

NOAA has numerous global data bases, and current research is underway to apply GIS technology to global studies. NGDC has developed a prototype GIS application for inventorying global aeromagnetic data. This application has the potential of being applied to any spatial data.

AISC has proposed using GISs for global land and marine monitoring. In the last year, breakthroughs were made using the PCI IBM AT computer to duplicate production operations performed initially on the Log E image processor and to develop new techniques and operations. The GIS has a capability of displaying over 40 overlays. This system includes numerous and diverse data sources: precipitation, satellite data, and resource maps. It is of interest to state and international users because of its low cost (within the range of $5-20,000) and flexibility. It is self-contained (other than power), user friendly, and has a fast response in modifying existing functions or implementing new ones. During 1988, AISC will test this system for land as well as for marine systems and attempt to include economic data for cost/benefit analysis.

NGDC has started to investigate potential applications of GISs in support of NOAA's Climate and Global Change Project. This is an interdisciplinary NASA/NOAA/USGS study of the global geosphere and biosphere.

Integrated GIS/Image Processing Systems. One of the major operational tasks in NOAA is to operate the civilian weather satellites. The primary application is the short and long term prediction of weather and climate. Other applications have evolved for the use of this data including: vegetation and forest fire monitoring, hydrologic forecasting, geologic evaluation. In all applications, satellite imagery is processed in raster form using commercial and public domain systems. This output is sometimes loaded into a raster GIS for various analytical tasks.

In many cases, ground based data are needed for additional analysis and also as ground truth for the satellite data. In most cases, these data are point observations or survey transects and are most easily used by vector systems. An interactive vector/raster-GIS/image processing system could allow easy transfer and analysis of data between systems. This problem is more than systems integration. It is a question of accurate integration of vector line to the cellular nature of a raster representation. A good example of this is the fitting of a vector coastline with topography represented in a gridded (raster) form. It is also a question of designing user-friendly, low-cost systems with increased storage and data processing potential.

Integration of Expert Systems and Artificial Intelligence. This would be the next logical step after the development of an integrated vector/raster GIS/DBMS. First and foremost, incorporation of AI would allow a greater efficiency in GIS analysis because this would eliminate much of the routine (and sometime arbitrary) tasks of classification, overlay, etc. Expert systems can query the data in a GIS, detect patterns in the spatial data, then use these patterns to guide further processing in the AI system (Hastings and Moll, 1986; Moll and Hastings, 1986). Future applications might also include scenario analyses and cost/benefit analysis for resource monitoring and development. (Hock, 1988)

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U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
Mission Statement

The U.S. Army Engineer Topographic Laboratories (USAETL) is the Army's center of expertise for researching and developing the wide range of topographic techniques and equipment needed to support the soldier in the field. USAETL supports the Army's modern weapons and command and control system through research and development in mapping, charting, terrain analysis, geodesy, remote sensing, point positioning, surveying, and land navigation. Additional research activities assess environmental effects on military equipment, develop topographic support systems and conduct global and regional terrain studies. In addition to directly supporting the Army in the field, USAETL also performs work for the Defense Advanced Research Projects Agency, the Defense Mapping Agency, the U.S. Army Materiel Command, and the U.S. Army Space Program Office. USAETL pioneered efforts and is on the leading edge of artificial intelligence research and in the application of digital image processing and computer image generation to enhance topographic support.

Geographic information systems (GISs) have been identified as one of the key technology areas that cuts across the organizational lines of USAETL's five laboratory elements. The GIS research program for USAETL is coordinated from the Geographic Systems Laboratory (GSL) whose primary mission is to develop military geographic information and reproduction systems.

The major developmental activity in GSL is automation of the manual terrain analysis process. The Digital Topographic Support System (DTSS), a computer system to be fielded in the early 1990s, will give topographic battalions a greatly improved terrain data manipulation capability. A geographic information system in DTSS will permit troops in the field to quickly generate products tailored to the commander's requirements. Geographic information systems' development and research at USAETL preceded the development of DTSS. Current research activities in GISs are in support of advanced DTSS capabilities and other Army systems which will use a GIS to manipulate digital terrain data and create special purpose terrain products. Specific areas of GIS research are the soldier-machine interface, data structures and exchange formats, and data processing techniques. GIS applications are used to support research in environmental effects data management, the development of tactical decision aids and electronic map display systems. Other USAETL laboratories are using GIS technology to support their research missions. The Terrain Analysis Center is modernizing their operations and is using a GIS to automate the process of preparing terrain area studies. The Topographic Developments Laboratory is using a GIS to support research in data capture techniques for terrain data base production. The Research Institute is using a GIS in artificial intelligence and feature extraction studies.

U.S. BUREAU OF THE CENSUS
Mission Statement

In its best interests, a civilized nation counts and profiles its people and institutions. Doing so ably and objectively is the abiding mission of the United States Census Bureau. We honor privacy, shun partisanship, invite scrutiny, and share our expertise globally. Striving to excel, we chronicle the Nation's past, describe its present, and illuminate its future.

The Census Bureau's success in accomplishing this mission rests not only on how well the staff collects and processes the data, but also on how well it links those data to the correct geographic areas for presentation of the results. For the Census Bureau to accomplish this broader mission, staff in its Geography Division must provide support in the form of maps and related geographic materials to help the data collection and processing staff do two basic jobs:

(1) Assign each housing unit and business establishment in the census or sample survey to the correct geographic location; for example, a city block.

(2) Classify the assigned locations into each of the tabulation areas recognized in that particular census or sample survey.

The Geography Division provides similar geographic support services for all of the Census Bureau's programs--the decennial census, the economic and agriculture censuses, the intercensal demographic estimates, and the current surveys. The scope and complexity of this geographic support task has changed over the decades, and the Census Bureau has changed its methodology for conducting censuses and surveys in response.

To meet the geographic support needs of the 1990 Decennial Census, the Census Bureau is building a national automated geographic (areal) and cartographic (map) data base called the TIGER File. This file uses a variety of new approaches to deal with the geographic problems associated with the production of over 300,000 individual enumerator assignment maps, appropriate maps for the field supervisory and office staff, maps to accompany the tabulated results, automated matching of addresses on the mailing lists the Census Bureau uses in many of its data collection activities, and the preparation of computer files that document the relationship between and among all the geographic tabluation units for the entire United States, its territories, and its possessions. (The latter is the same set of geographic units that would be seen by looking at a full set of Census Bureau maps spliced together into a single sheet.)

The TIGER File can serve as a major component in a geographic information system. The principle cartographic components of the TIGER File are the map features (streets,

rivers, railroads, and so forth) that appear on a traditional map, captured in computer-readable form. The Census Bureau accomplished this task by establishing a cooperative agreement with the U.S. Geological Survey to prepare the initial digital base file. Appended to each of these map features (lines) is various geographic information that also serves as a cartographic enhancement; for example, feature names, address ranges, ZIP codes, and so forth.

The network of lines formed by these features encloses spaces or areas. The TIGER File contains, appended to these area records, a set of geographic identifiers that also serve as cartographic enhancements; for example, 1990 census block numbers, census tract numbers, city codes, township codes, metropolitan statistical area codes, congressional district codes, and so forth. The TIGER File, in fact, contains two sets of such codes: one representing the geography at the time of the 1980 census and another representing the geography at the time of the 1990 census. Thus, the first comparison that can be made in a GIS environment is one that determines areal differences from one census to the next.

From a classic GIS standpoint, the geographic area codes provide the mechanism to link the TIGER File's cartographic base to other Census Bureau statistical data sets such as the data tabulations from the 1980 decennial census (recorded on the several 1980 census summary tape files), the 1990 decennial census, and the numerous data sets from the several economic, agriculture, and governments censuses. (The definition of the geographic areas represented in the latter censuses may be slightly different than what existed in either the 1980 or the 1990 decennial censuses.)

The TIGER Files carry latitude and longitude coordinate values for the intersections and end points of the lines comprising the map. These latitude and longitude coordinates permit a GIS to relate the underlying cartographic framework of the TIGER File to data sets from other agencies that are defined by coordinate values; for example, the land use/land cover data sets available from the U.S. Geological Survey, the water resources data and geological data sets also available from the U.S. Geological Survey, the soil data sets from the Department of Agriculture's Soil Conservation Service, the Landsat imagery available from the EOSAT Corporation, and numerous data sets available from state, county and local units of government that have developed digital files to represent information that interests them.

The Census Bureau views the successful exchange of data between Federal agencies and the private sector as an important aspect in the developing GIS field. The ease of data exchange and the adoption of data formatting standards will be of vital concern to all GIS users. To facilitate this process, the Census Bureau is currently an active participant in the Task Force

establishing a draft digital cartographic data standard.

Beyond an exchange standard, the need is to evaluate the potential applications of computer processing systems to manipulate these massive data sets simultaneously for large geographic areas (regions, states, and so forth). The purpose of this manipulation is to look for relationships, dependencies, and so forth among the data sets.

U.S. ENVIRONMENTAL PROTECTION AGENCY
Mission Statement

The U.S. Environmental Protection Agency (EPA) coordinates governmental action to assure the protection of the environment by abating and controlling pollution on a systematic basis. The EPA undertakes a variety of research, monitoring, standard setting, and enforcement activities related to pollution abatement and control to provide for the treatment of the environment as a single interrelated system.

The Environmental Protection Agency has begun to explore the use of geographic information systems in support of its chartered mission. Currently the Agency has four active GISs. Each of these systems is being employed in support of very diverse projects and programs. The Environmental Research Laboratory in Corvallis, OR, uses a GIS to study the ecological effects of acidic deposition and other anthropogenic stressors. The Cheasapeake Bay Program in Annapolis, MD, is using a GIS in the management of estuarine and coastal ecosystems. EPA Region 4 in Atlanta, GA, employs a GIS to determine the risk to drinking water sources and urban populations from hazardous waste facilities.

The Environmental Monitoring System Laboratory in Las Vegas, NV, has been designed as the EPA's Center of Excellence for GIS technology. Its mission is to explore new and unique GIS applications by interfacing current technology with remote sensing and artificial intelligence systems. Another important aspect of the Laboratory's mission is to demonstrate the use of the technology to the EPA Program Offices and ten regions.

The future of GIS technology in the EPA is promising. As the regional demonstration projects go forward, managers are discovering that this technology provides an excellant platform upon which to base monitoring programs and management plans. As a decision support system, GIS technology will play an intregal part in the management of future EPA programs.

U.S. FOREST SERVICE
Mission Statement

The Forest Service, U.S. Department of Agriculture, provides leadership in the management, protection, and use of the Nation's forests and rangelands, almost two-thirds of the Nation's federally owned lands.

The agency is dedicated to multiple-use management of these lands for sustained yields of renewable resources such as water, forage, wildlife, wood, and recreation. Under this management concept, the best combination of uses benefits the American people and assures the productivity of the land and quality of the environment for present and future generations.

The Forest Service performs many different natural resource tasks, ranging from improving the beauty and productivity of the forests, to showing strip miners how to rehabilitate the land, to managing much of the Nation's wilderness.

The Forest Service relies on long-range program planning to assure that the resource demands placed on the Nation's forests and rangelands are met and the productivity and environmental quality of these lands are maintained.

The Forest Service is a leader in the conservation and wise use of the Nation's forests and rangelands. The agency manages the National Forests and Grasslands, cooperates with the States to help private landowners apply good forest practices on their lands, and does research to find better ways to manage and use our natural resources.

The Forest Service operates a forestry research program of unparalleled size and scope. The program provides scientific and technical knowledge needed to protect America's natural resources on all lands, to gain maximum benefits from their use, and to minimize the effects of human intervention on the environment.

The principal areas of Forest Service research are land and resource protection, resource management, and wood utilization. The agency performs research on forest tree improvement, growth, and harvesting; forest economics; protection of forests from fire, diseases, and pests; and management and improvement of rangelands. Other subjects include management and improvement of wildlife and fish habitats; forest recreation and wilderness management; protection and management of watersheds; urban forestry; rehabilitation of lands disturbed by mining; forest engineering; and efficient marketing and use of forest products.

There are many areas requiring further GIS research. Fire and atmospheric sciences is one such area. More research is needed for prescribed fire studies and for fire prediction, prevention, and control through modeling and real time monitoring.

More work needs to be done in insect and disease research, specifically pest and pathogen prediction, modeling, prevention, and control, as well as the development of environmentally safe and effective strategies for pest management.

There are research needs in inventory and analysis, such as the development of comprehensive analyses and monitoring of the characteristics of forest land resources for use in making decisions about expanding industry, managing financial investments, designing State forestry programs, and creating public and private forestry policies.

There is need for timber management research in the development of improved silvicultural alternatives to increase the productivity and multiple use of forest lands.

More research should be done on watershed rehabilitation, in developing and testing of new methods for rehabilitating lands disturbed by surface mining and for protecting, managing, and improving forest and rangeland watersheds, as well as in developing relationships between atmospheric deposition, forest health, and watershed conditions.

There are GIS research needs in the area of wildlife, range, and fish habitats, such as developing methods to improve wildlife and fish habitat, range conditions and productivity, soil stability and vegetation cover, and to integrate wildlife, fish, and livestock with other forest and rangeland uses. Also, much work has still to be done in understanding the complex relationships among habitat quality, growth, and response of vegetation to defoliation, other land uses, and wildlife and fish populations so that diverse and well-distributed habitats, productive rangeland ecosystems, and protection and improvement of forage and related resources are assured.

Another opportunity for research is forest recreation, developing techniques to manage vegetation in and near urban areas for optimum economic, social, and environmental benefits.

And finally, there are research needs in the area of forest products and harvesting. This includes the development of timber harvesting and transporting systems that are economical and environmentally acceptable, and the facilitation of forest management and environmental protection through improved harvesting of wood.

U.S GEOLOGICAL SURVEY
Mission Statement and Summary of GIS Activities

The U.S. Geological Survey (USGS) conducts and sponsors research in geology, geography, hydrology, cartography, and related sciences. It produces and updates geographic, cartographic, and remotely sensed information in graphic and digital forms; describes the onshore and offshore geologic framework to develop an understanding of its formation; assesses energy and mineral resources, determines their origin and manner of occurrence, and develops techniques for their discovery; collects and analyzes data on the quantity and quality of surface water, ground water, water use, and precipitation; assesses water resources to develop an understanding of the impact of human activities and natural phenomena on hydrologic systems; evaluates hazards associated with earthquakes, volcanoes, floods, droughts, toxic materials, landslides, subsidence, and other ground failures, and develops methods for hazards prediction; participates in the exploration of space and prepares geologic and other maps of the planets and their satellites; coordinates topographic, geologic, and land use mapping, digital cartography, and water-data activities; develops new technologies for the collection, coordination, and interpretation of earth science data; and provides scientific support and technical advice for legislative, regulatory, and management decisions.

General areas of GIS research interest include techniques for the exchange of digital spatial data; advanced computer system architecture; improved data structures; three dimensional volumetric modeling of subsurface features; terrain analysis; spatial dynamics and time series data; very large data systems; knowledge based inference models; expert systems; natural query languages; and advanced spatial data handling techniques.

A special area of concern is data exchange. Considerable data are being digitized at numerous locations throughout the country by, or at the request of, Federal, State, and local agencies. With the proliferation of GIS software and methods for inputting and representing spatial information, the exchange of data between systems has become increasingly difficult. Digitizing specifications and procedures should be investigated in an effort to establish greater uniformity and compatibility among data bases. In addition, standards are also needed for data interchange among organizations and the transfer of data between software systems.

The Information Systems Division is working with and assessing advanced computer hardware capabilities such as optical disks and concurrent processors; GIS applications using existing microcomputer technology; an Earth Science Information Network to link a series of information data bases with a number of public contact points; an Earth Science Data Directory to provide online access to USGS's central repository of detailed information about earth science data, and the feasibility of combining artificial

intelligence wlth existing GIS technology.

The Geologic Division is using GIS capabilities for geologic/geographic information management, manipulation, and display of thematic data. The GIS capabilities employed include gridding, contouring, feature extraction, overlay, linking of locations to attribute data, and data display using both raster and vector representations. The GIS capabilities match closely the general requirements for processing geologic data, including the need to manage very large data sets having diverse attribute data and the facility for updating bases as new observations are made and new data are collected.

The National Mapping Division is developing a National Digital Cartographic Data Base (NDCDB), and is conducting basic and applied research to develop advanced techniques for spatial data display, manipulation, and analysis. Research in GIS technology includes spatial data base design, modeling of cartographic entities and objects, implementation of prototype spatial operators, development of a standard exchange format for geographic data, evaluation of existing GIS technology, and development of an advanced vector/raster data interface.

The Water Resources Division has installed GIS hardware and software at 24 locations across the United States and linked all of their facilities with an earth science Distributed Informatlon System network. WRD applications include analysis and production of the National Water Summary; boundary mapping for irrigation water rights; support of ground water modeling studies; flood, stream, flow and water quality studies, and analysis of aquifer and water use data bases.

PLENARY SESSION 2. GEOGRAPHIC INFORMATION SYSTEMS RESEARCH AGENDA:

THE SCIENTIFIC COMMUNITY PERSPECTIVE

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PLENARY SESSION 2

GEOGRAPHIC INFORMATION SYSTEMS RESEARCH AGENDA: THE SCIENTIFIC COMMUNITY PERSPECTIVE

CHAIR: David Cowens, University of South Carolina

PANEL: Waldo R. Tobler, University of California, Santa Barbara
David Rhind, Birkbeck College/UK
John Bossler, Ohio State University
Michael Goodchild, University of Western Ontario

Waldo Tobler:

I'm supposed to talk about the research agenda, and it's not the kind of topic that I like to talk about because you never know whether you've got it right. It's not really my kind of paper. But in trying to think this over, I came to the realization that the year 2000 is only 12 years away, and I tried to ask myself what kinds of problems need to be solved by then. I'm not going to try and discuss such obvious things as the application of AI or expert systems (this is going to be discussed in another panel later in the next day or so), nor data structures, nor a lot of other possible topics. But it occurred to me that there are two different kinds of issues that you could address in thinking about this kind of question.

These two separate issues are the technical problems and the conceptual problems. The distinction is not really so nice and neat as I've made it. They merge into each other and they influence each other. In my opinion, the technical problems are much easier. And I've made a short shopping list of some of these things. Under error structures (which Mike Goodchild knows more about than I do), I've been thinking about how to display the errors on a map. One conventional method is the reliability diagram, but it seems to me there are several other things you could do. For example, if you have a computer with two frame buffers, you can flip back and forth between two pictures slightly out of register with each other by different amounts in different parts and get kind of an unstable image. Too often we try to make nice, neat lines when really we don't have that kind of data. You can do the same thing with fuzzy maps by defocusing under program control on a lot of CRTs. If you saw the display upstairs, there is a nice SPOT satellite picture of Washington, D.C.; and if you look at it carefully, it's fuzzy. I think that's great because it really tells you that it's not all there. And I think we should do a little more of that with the maps. If you work with photography you know that if you enlarge a picture, and enlarge it, and enlarge it, you eventually reach a point of what's called "empty magnification." There just is not anything more to be seen, and enlarging it makes it worse. I think we could perhaps use ideas

like that. Also, we could modulate the background color. This I think would also be very easy to do on a CRT. That's one kind of issue relating to displays.

Another topic is what I briefly call "the algebra of maps." George Boole in his book on "The Laws of Thought" in the last century invented a new algebra which is now called Boolean algebra. In the 1960s, geographers were trying to do this sort of thing, and it seems to be revived now. Some of the work that Professor Berry at Yale has recently published reminds me a great deal of work that was done in the 1960s by geographers. If you look at a geographic information system and look at the set of operations that can be done with it, you can classify those in several ways. One set of things are unary operators; that is, if you have an elevation model or terrain model, you have a single number at each point. You can take the square root of that number, and that's independent of what's happening in other places. It's independent of any other data. On the other hand, you could do binary operations relating, say, two overlays or images. People have realized for many years that there are also neighborhood operators, and I think people are learning more and more that one also wants to incorporate long range interactions, potential models if you will, or macro models, as well as just local point and neighborhood operators. I think by the year 2000 we'll have a pretty good handle on the algebra of maps although there may be some more subtle problems.

Another problem that I think is mostly a technical problem but may be more difficult, is the question of resolution or scale dependence. Everybody talks about resolution. Everybody talks about scale. Hardly anybody ever defines it. My definition of the resolution of a data set is that it's the total area of observation (or the domain of observation) divided by the number of observations. Then you have to take the root (square root in two dimensions, cubed root in three dimensions, and so on) to normalize it. This works for point data. It works for line data. It works for area data. And just having a simple definition like that allows you to compare different data sets. And then you can start asking whether the operations which we do on these data are really working at the same resolution. And that brings up other kinds of questions like what happens when we abstract? Just like the Reader's Digest when it condenses a book, when we simplify a map or a data set, we're doing some kind of abstraction. Does that lower the resolution? There are tons of questions in this area.

There's another problem that's been of interest to me because of an interest in medical geography. When you get a map showing cancer rates, don't believe it. The reason is the rate depends on the areal unit used, and you can very easily change the disease rate by just changing the geographic data collection area. These resels, as I call them, geographic collection areas or resolution elements, influence the result we get. And you can come up with any rate you want by simply changing the base.

Oppenshaw in Great Britain has shown in some detail how the zonal system, as he calls it, influences the results we get. He blames it on the zonal system. I blame it on the methods we use. If you look at what physicists do, they work with methods that are coordinate invariant, and any data collection system that we use in geography--census tracts for example--is kind of a coordinate system. We really should invent methods that are completely independent of the coordinate system. This is why physicists use the tensor methods; it doesn't matter whether they use polar coordinates, rectangular coordinates, or some other coordinates, they get the same answer. We need to do the same thing.

Related to this same problem is the problem of converting data from one set of resels to another; census tracts to school districts, for example. I think that's a problem which can be solved in a satisfactory manner. As a scientist, I assume all data are to some extent wrong, so I'm not too worried about the fact that there's going to be a little mismatch. Whether this is important depends on the context of the problem.

These are kinds of unsolved technical problems that I see as being relatively easy to work with. There are some more conceptual problems, and these have to do more with how we look at the world, what kind of problems we think are interesting, and I think that's very important. For example, virtually every statistical package you purchase these days has a time series analysis package tacked onto the end of it. None of them allow for spatial series analysis. Now, why can't we do that? Couldn't we just attach a little module that adjusts for regional trends just like people adjust for seasonal trends? I think we could. If we want to compare two maps, couldn't we just attach a little package to do cross spectral or cross coherence analysis, the technical proper way of comparing maps? Why don't the GISs do this? I think it's because of the kinds of questions that are asked by the people who use GISs. Obviously, one could extend all of this to space/time modeling of the geographical environment. Modeling and real time monitoring must be coupled--an ozone hole in Antartica is only discovered as an anomaly--a departure from an expectation or model. Hardly any GISs today are real time and dynamic. If you, for example, had the complete flow of all telephone messages throughout the country every five minutes or so for a hundred years, this would give us nice data for a short animated movie. Maybe we'd discover interesting things by looking at that kind of data. I suspect we'd notice how our society is changing by visualizations like that.

Continuing in the same vein, how you look at things is important. One of the classic characterizations of data in this field is as "points, lines, and areas." I think that's a pretty primitive model. The data in many cases are hierarchical or more complicated. Instead of thinking of "points, lines, and areas," I personally find it useful to think of the data in many, many different ways simultaneously, just like when I pick up a geologic specimen and I can look at it from several different

points of view. One of the points of view I find useful, and it's the only one I'll talk about right now, is to think in terms of spatial "fields," a term used in mathematics and physics. Fields can be either discrete or continuous. Discrete fields can be binary or unary when the data are categorical; or, if you have something like a DTM (topographic data) in which you have one single number at every location, that's called a scalar field and can be considered a sample from a continuum. Then the single number exists everywhere; whether you know its value everywhere or not is another matter. Then there are vector fields and tensor fields. If you take the slope, for example, of topographic terrain, you get a vector field. If you take the slope of a vector field, you get a tensor field, all of the component partial derivatives. And then you have to ask questions, such as, is this really a differentiable continuous field? Or, for example, if you have the incidence of disease by the coordinates of the house in which a deceased person was, how do you convert that to densities? Is it a differentiable scalar field? I guess the simplest way I can characterize all of this is to repeat the question that Lewis Richardson asked some time ago about meteorology. He asked the question, "Does the wind have a velocity?" It was a serious scientific question. Wind, after all, is made up of the movement of discrete air molecules, and velocity is a derivative with respect to time. How do you take a velocity, how do you take a derivative, of discrete particles? I think you can see the dilemma. We run into this kind of problem in geography very, very frequently; they also occur and have been studied in many other fields. The problem relates to the so-called continuum hypothesis. Anyway, I'm suggesting that looking at our data as a continuum is sometimes very useful. We must go beyond "points, lines, and areas."

Finally, it seems to me that the objectives which we have clearly influence the types of questions that we ask. Much of the GIS field is devoted to managerial problems rather than scientific questions. The GIS focus in management is not on new knowledge, so I ask myself: How would a geographer like Walter Christaller (who invented central place theory), how would he have used a GIS? How would a world famous geographer like Torsten Hagerstrand have found a GIS system useful in the areas that he explored? In other words, can we use GISs to discover theory, to discover new ways of looking at things, to discover new insights, to verify hypothesis?

By the year 2000, 12 years from now, we will have tons of data (but weighing only grams in electronic form). We'll have lots and lots and lots of data. Look at the rate at which it's accumulating now and extrapolate for 12 years. But, I conclude that what a GIS should be like then, or what a GIS will be like then, depends very much on how we approach the subject today.

David Rhind:

This is somewhat more mundane perhaps than Waldo's talk, but nonetheless, I think it may be useful in bridging between what we heard earlier today, when the government agencies talked about their perceptions of GIS research needs, and what the academic community thinks is important.

I'm going to be talking mostly about Britain, but much of what I say also applies in Europe. Perhaps the first point is to remind ourselves that Europe has 30-odd percent more population than the U.S., has almost as varied a physical environment, and has arguably a much, much more varied social, legal, and cultural environment. In other words, it would not be at all surprising if many of the things we found on a check list for research agendas in different countries in Europe was significantly different. In practice, however, that is not the case. Let me now describe the two parts of what I'm going to say. First, I will summarize the research agenda as seen from the U.K., and secondly, turning it on its head, examine what GISs can do for research elsewhere. The latter is a very significant problem. I should say that GISs are now in my own country widely regarded by quite reputable scientists--physicists and the like--as being a very, very important enabling technology. So what can it enable? What are its limitations? We'll come to that at the end.

Back, then, to the U.K. research agenda. It has to be said that this is not simply an idea off the top of my head. Earlier this year, a report was published that I know many of you here have actually read. The report is that of a U.K. government Committee of Enquiry, chaired by Lord Chorley (who will be here tomorrow).

The background to this is quite interesting and not irrelevant. In 1979, there was a major report in the U.K. which looked at the national mapping organization from top to bottom. They--the Ordinance Survey--had essentially finished their work: they had mapped all the country. Government then had to face the question of what to do with a national mapping organization when the work was complete. The answer, of course, was to keep the maps up-to-date. That particular document--the Serpell Report--had one chapter (out of ten) on digital mapping even though Ordinance Survey had been working in the field for ten years by then. Four years later, another report--this time it was produced by the House of Lords' Select Committee on Science and Technology (which is perhaps equivalent to your Senate Committees)--looked at the relationship between remote sensing and digital mapping, seeing these as complementary sources of data and technology. But what perhaps was most important in that particular report was that, at the end of it, the Committee said (in effect), "We've only just realized that we're scratching the surface. Everybody uses geographical information. It's being produced by virtually every government department, being produced

without thought of how it can be used together or, indeed, without any form of standardization. Someone had better have a look at this." And, to our great astonishment, the government said, "That seems harmless enough. We'll set up a Committee of Enquiry to look into it."

That Committee of Enquiry was chaired by Lord Chorley (and I had the honor to be a member of it). The committee reported earlier this year. What I'm going to be talking about now comes more or less directly out of the report. I should say that the report is based on evidence sent in from over 400 organizations; people for 20-odd organizations were interviewed; visits were made to such eminent places as the USGS and various organizations in Europe. So the research agenda is not entirely our invention! Now what comes out of all this?

The first thing, I think, is to declare off-limits at least some R&D--because we've got better things to do and we aren't the right people to do it. The size of the domestic market for compact disks, for CDV, and many other things of this sort is going to mean that we can ride on the back of these technologies--but we are unlikely in many cases to be able to significantly influence them ourselves as cartographers, geographers, or surveyors.

I note a few interesting exceptions: Peter Mueller's work on 2 1/2 Dimension real time simulation using transputers is, I think, relevant to quite a number of us so there is an academic in a surveying department making major contributions. But, by and large, I think you can write off that particular area of hardware research and system software creation as not appropriate for university researchers in surveying and related fields.

The next thing to consider is the proper research agenda. Perhaps the single most important issue that came out in all of our work was the need to put some "intelligence" into the mindless computer programs that we have at the present time. By and large, most of the computer software that we have access to is little more sophisticated than what goes in computing bankrolls and payrolls. There are a number of obvious areas where human skills, however, can easily be fed in, whether it's in some kind of simple rule-based system or whether it's something more sophisticated than that.

In the U.K. at least, analog to digital data conversion is very important. We have nearly a quarter of a million different maps. By being so exceedingly clever as to finish our complete mapping coverage in 1979, we managed to complete all of this in paper map form; we therefore have a quarter of a million different map sheets which we would like to have in computer form, preferably in a way so that we can use them for tasks in addition to simply to making new identical pictures with them. And to do that taking into account the characteristics of the data (most of these are urban maps), and use that intelligently

to improve the quality and reduce the cost of the end product is something that is going to require (in our terminology) Intelligent Knowledge-Based Systems.

Data integration procedures have already been cited as a research area in the crudest sense; let's pour some vector data on top of raster data and do something with it, whatever that means! I have to confess to a degree of boredom about that, but perhaps that's just because I've been to lots of conferences where people have said that's terribly important! Data structures and search algorithms are again, terribly important but highly boring. That was last year's research topic... .

Generalization, however, is much more interesting. Unfortunately, most people who are doing any work on generalization are doing it totally, utterly the wrong way because it can only sensibly be done upon real world objects, as opposed to cartographic features. So--for instance--to generalize contours one at a time, taking no account of the local form of the land surface, is manifest nonsense.

Spatial statistical descripters of the result of data integration (our term is error train analysis) will be covered by Michael Goodchild. This is an important--even vital--area of research.

Spatial modeling superstructures to GISs form anothers "hot" area. Again, I hope Michael will talk about that because he is better able than most to do it. It's clearly going to be absolutely critical: at the present time, most GISs are nothing more than data scavengers. They have very little ability to model the world even though they are competent database retrieval mechanisms.

Natural language interfaces are also a very exciting area of research. I'm not sure I understand them, so therefore they are very exciting indeed! And said by many people to be the most important.

In addition, there are three things that seem to me to be (in the longer term, perhaps) much more important than some of the technical issues that we've addressed up till now. The top and bottom of our problem is that most people want to use the GIS provided and have no understanding of the complications of analyzing spatial (or geographical) data. Under certain circumstances, you can generate whatever sorts of results you want from given input data by varying the resolution used, the spatial positioning and the analysis algorithm. Since there are relatively few people around who understand very much about theory as well as data handling, clearly we have to build systems which are as far as possible idiot-proof. I'm not talking about cadastral systems which, in the main, simply ask for "what is the situation at this particular place?" but rather am considering those systems which have higher levels of manipulation power. At

the present time we are building an environmental information system for the whole of the European community, and believe me--intelligent as they are--the bureaucrats really do need the equivalent of a man with a red flag walking in front of a car to make damn sure that people do not mishandle the system and database. The easier it is to use, the bigger nonsense will be generated. So this problem has to be sorted out by including "best practice" in our "intelligent" system.

If part of the problem is that we don't have people who know what they're doing, we need to teach more. Yet, even if Waldo was made to teach 60 hours a week, that still wouldn't be enough. Even if we replicated, cloned Waldo across the United States and spread him elsewhere, we still wouldn't have enough people to meet the teaching needs in this rapidly expanding area. The only answers is an on-line, "intelligent" tutor.

Visualization research is something of a mess in that many of the psychometric studies of the last 20-30 years have proved precisely nothing. And yet here we are, investing enormous resources in graphics displays of one kind or another and--providing the colors look right--things are fine (at least so many users believe). It would be nice to know that results were a little more meaningful than that; we should actually be able to tailor our output to be effective and efficient for different tasks and users. I think that does suggest that we need some research in the visualization area.

Moving still further from the technical area into other forms of research required to enhance the use of GISs, the legal aspects of introducing these GISs will be, in my view, absolutely critical. If you drive the wrong way down a one-way street and get mangled and you've done that because you've been told to drive that way by your navigation system, who's responsible? Again, some data are highly confidential in disaggregated form but not confidential and valuable when geographically aggregated to such a particular purpose. We are trying to build, using both hardware and software, a secure system for anyone to explore our census database at the individual household response level and (in interactive fashion) to generate whatever tables they wish out of that with appropriate data suppression and checking by a rules-based system: the critical thing is that no one should be able to see details of individual households.

Copyright, at least in my country (perhaps at the other extreme from yours) is a most critical issue. Who owns the data? How much money can you make out of it? (I understand that it's also beginning to be important in your own country.) It's certainly important in many other areas of the world, especially in Europe.

Clearly, in these areas we need some research. You can't just listen to lawyers and believe what they say!

Now let me turn to the organizational aspects. However mundane that is, GISs are not successful unless they can actually be made to fit into pre-existing organizations, a point I think that Nick Chrisman makes in a paper to be given later in the week. So that has to be looked at by people who are skilled in the structure and functioning of organizations.

Finally, cost-benefit methodologies. Most of the stuff that I have seen in this area is a load of junk in terms of being able to justify the benefits as being worthwhile of introducing some GIS. I don't think in many cases that it was wrong to introduce the systems described by the authors, but certainly the way in which we can demonstrate what is appropriate and what is inappropriate seems to me not to be very effective at the present time.

Finally, let's turn away from research in GISs and look at what GISs can do for other research. This is no problem if you regard GISs simply as a mechanism for carrying out an inventory and for monitoring change: we can easily cope with that. But the trouble is--and especially in the social sciences--that the whole basis of the research changes periodically. We already have good evidence of the way in which people built GISs ten years ago. It actually perturbed social science, influenced many of the conclusions of the day, and then, quite suddenly, the particular topics which people worked on have shifted to a completely different area which does not use existing-type and laboratory-compiled GISs. In short, the research paradigm changed. The situation seems to me much more stable in the "hard sciences" and the environmental sciences, but I leave you--if I may--with a question which is not what we can do for GISs but rather what can GISs do for research in the environment and the other disciplines we're dealing with? I believe it is not at all clear that most of that research can benefit on a continuing basis from the kinds of GISs which we are building at the present time. This is manifestly true even at the trivial level of new research needing new variables, hitherto uncollected. How do we minimize this problem?--by global sharing of research databases?

John Bossler:

I want to talk to you for a few minutes about an extremely important scientific endeavor which I think is something that you can hang your hat on in the next few years. I must apologize for a certain lack of information when I put the slides together which I have since discovered and will allude to. On the other hand, I don't think that I would change my final recommendation. I wish to talk today about the IGBP, the International Geosphere Biosphere Program of the conglomerate scientific society known as the Council of International Scientific Unions (ICSU).

ICSU is made up of a number of huge organizations, in one of which I'm very active, the IUGG. It in turn is made up of many

organizations, in one of which I'm active, the IAG, etc. Under ICSU is also something that most of you belong to, the International Geographical Union. In any event, in 1986, ICSU initiated the IGBP. This is a major international scientific program, the likes of which have their reminiscences in GARP, BOMEX, IGY, and from what I see happening, it may in fact turn out to be one of the largest international programs.

It is based on the recommendations by the now president of ICSU, Sir John Kendrew, and planning for it began in 1984. The objective is shown below:

International Geosphere-Biosphere Program
A Study of Global Change

- Initiated September 1986 by ICSU.
- Based on recommendations by Sir John Kendrew, President of ICSU, et al.
- Planning began in 1984.
- Objective: "To describe and understand the interactive physical, chemical, and biological processes that regulate the total earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human actions."

There were four planning groups that provided recommendations for the IGBP as an international program. These planning groups were:

Four Key Planning Groups

- Terrestrial Ecosystems and Atmospheric Interactions
- Marine Ecosystems and Atmospheric Interactions
- Geological Processes-Past and Present
- Upper Atmosphere and Near Space Environment

You can see by the very names of those working groups or planning groups that the program is extremely broad and important.

There is now a special committee for the IGBP under ICSU. There must be dozens of committees related to the ICSU IGBP program, but the one that will drive the program, in my opinion, and the one that is most important is the special committee headed by Dr. James McCarthy of Harvard, a zoologist. Within that special committee, there are coordinating panels and working groups. These are shown below:

Working Groups/Coordinating Panels

Coordinating Panels
- o Terrestrial Biosphere
- o Marine Biosphere
- o Biospheric Aspects of Hydrological Cycle
- o Effects of Climate Change on Terrestrial Ecosystems

Working Groups
- o Global Geosphere-Biosphere Modeling
- o Data and Information Systems
- o Techniques for Extracting Environmental Data of the Past
- o Geo-Biosphere Observations

I want to focus again obviously on the second working group, data and information systems. The charge for the committee is for both real time and past changes. They plan a conference in August of 1988, and the composition of the committee is shown below.

Data and Information Systems

- o Both real time and reconstruction of past changes
- o Study Conference in August, 1988
- o S.I. Rasool (Chairman)
  S. Dyck
  W.S. Fyfe
  V.A. Troitskaya

The chair of the committee is S. I. Rasool, well known to most of you who are involved in remote sensing, and he is from the United States. The rest of the committee is from other countries.

That committee will consider remote sensing and surface observing networks, (to me read interface GIS with remote sensing); the selection of key parameters that need to be documented, (to me read format and data description requirements); assessment of data sets already available; specification of requirements for calibration and intercomparison; preparation of appropriate data sets; and the development and methods to obtain remote sensing data, avenues of data dissemination.

Will Consider

- Remote sensing and surface observing networks.
- The selection of key parameters that need to be documented.
- Assessment of data sets already available.
- Specifications of requirements for calibration and intercomparison.
- The preparation of appropriate data sets.
- Development of methods to obtain remote-sensing data and to make these data accessible to the international scientific community.
- Avenues of rapid data dissemination.

As I mentioned, I learned only a few days before coming here that the IGU and its research committee have put forth a proposal to help assist in the data management aspects of the IGBP. I didn't know that when I put this together. Nonetheless, I think that someone from the research committee of the IGU or somebody in a leadership role in GISs should be placed on the Data and Information Committee of the IGBP. This is an extraordinary opportunity for you all (and me) who are involved in GISs, and it follows the track that initiated GISs, that is, the management of remote sensing information. And I think we should become proactive. Perhaps we have been. Nonetheless, I believe that the special committee for the IGBP will drive the program, and I think in particular the GIS community should have representation on the working group on data and information systems.

I bring this to your attention because I'm in the rather unique position of being a member of the National Academy of Sciences Advisory Committee to ICSU and in that capacity I stand ready to help the GIS community interact most appropriately with the IGBP.

Michael Goodchild:

I'd like to start by asking what the driving forces are in the scientific agenda. In other words, what are the social needs we're trying to satisfy by setting up a scientific agenda for research in GISs? I would like to make three suggestions about the motivating forces. All of these have been touched on to some extent but I think this is a slightly different way of looking at things.

The first is the gap which is evident between technology on the one hand and application on the other. I think many of us are aware that there are, on the technology side, very effective and powerful tools available, and yet there seems to be a gap between them and the actual applications that we can successfully carry out using GIS technology. To some extent this has to do also with theory, and the fact that we've been very industrious

in developing theory in modeling and analysis which has not managed to reach the kinds of applications we might have liked. So there seem to be impediments to the application of theory and technology in successful ways. That's the first of my three driving forces.

The second is that there is evidently a tremendous amount of interest in GISs, and there's been no shortage of statistics on the number of conferences which are running, the number of people that come to conferences, the amount of interest which is evidently present in the decision making, resource management, and government agencies in making use of this technology. But again the necessary adaptation of tools and technology isn't yet present. We have not yet come to grips with making the kinds of improvements in the technology which are necessary to meet the aspirations of the people who are clearly interested in using GISs.

Then the third driving force is what's already been referred to as the issue of enabling technology. A GIS is clearly a multi-disciplinary tool. It has the potential to play a role in a variety of disciplines in a variety of branches of science. It's a tremendously powerful tool and yet because it seems to lack a strong theoretical, philosophical, and historical basis, it doesn't appear as a standard discipline and so it somehow falls in the gaps between the current disciplines. So the third driving force is the need to establish GIS technology as a useful tool within the broader scientific scheme of things.

So if those are the three driving forces, then what's the appropriate response on the part of the scientific community? I think the answer is first to observe that it clearly requires two kinds of responses, and this is typical of science in general. It requires a response in being able to do things that we already know how to do, including of course the automation of things that are currently done by hand. But it also requires a response in developing new things. So science is performing its usual dual function in both doing things better and doing new things.

In both areas, the three driving forces seem to me to suggest that the kind of research we're looking for is research on the use of the technologies, not research on the technology itself. David Rhind has already referred to the fact that basic research on the hardware and perhaps even the software is not really the domain of the community that's assembled here. Rather we have the skills to make better use of the technology and to do research which is designed to improve the technology by making it more easy to use.

With that kind of preamble I'd like to identify particular areas, and again I'm conscious of the need not to overlap what's already been said, so these are I hope to some extent things that haven't yet been covered.

The first one is the hardware and software field, and I think essentially we're constrained by the work being done in other fields and in industry. The basic equation we have to face is that which relates response time on the one hand, functionality on the second hand, and data volume on the third. It's clearly impossible to satisfy everybody's demands for fast response time with large data sets, and the ability to handle a very broad range of kinds of analysis. It's quite clear that the kinds of analysis that we're talking about for GIS are much broader than those conventionally considered in an analysis package.

One of the three elements has to be sacrificed. On the one hand if one wants maximum functionality for very large data sets, one has to give up response time; it's very difficult to use a system which has a very broad functionality in a way which is immediately responsive. If one is concerned with response time and data volume, then one has to give up on functionality, so that systems which handle the very largest volumes are forced to do so in a very limited functional way.

Perhaps as academics we can consider dropping the data volume necessity, arguing that we can design systems which are both very broadly functional and have very fast response time if we're willing to assume that we don't have to look at realistic-size data sets.

The second element is uncertainty, and under this heading I'd lump a large number of aspects of the research agenda. The one that interests me most is the question of error and accuracy, and here I'd like to observe, and I think this is fairly broadly accepted, that we lack models of spatial data on which we can build such things as indices of uncertainty, confidence limits, and statistical tests. The dream that many of us have accepted is that we might one day see a GIS which produced measures of uncertainty or confidence limits with all of its products, so that in measuring the area of a polygon, it would at the same time produce the measure of uncertainty in that area. I think it's trivial at the present time to observe that that's not available in any GIS, and yet that sort of thing will be immensely valuable. I talked to a forester not so long ago about the estimates of wood yield that he got out of his GIS, and I asked him what level of accuracy he got, and he said, "10 percent." And I was amazed because my understanding of the accuracy of typical geographical data would certainly not support that, so I said, "How did you manage to come up with that figure?" And he said, "Well, I take what the GIS says, and then I subtract 10 percent."

What we lack in this connection and what will solve this problem is a series of statistical tools based on stochastic processes which can be used to model error. The analogy to conventional measures is that we lack the equivalent to the normal distribution which we can use to put confidence limits on

results and to construct things like t-tests. None of the equivalents is available in the GIS field at the present time. And that to me is a very major area of the research agenda.

The second point concerns aggregation and generalization. One of the strong points in favor of GISs is its scale-free nature. It ought to be possible to work freely across scales to extract the same objects at different scales, and yet we find that remarkably difficult to do, because we lack the rules which would allow us to take an object at one scale and generalize it or artificially give it detail at another scale.

The third element of the uncertainty agenda is the issue that Waldo has already alluded to which is the question of variable reporting zones. It's amazingly difficult in the social sciences, because of changing reporting zones, and irregularly produced data, to do anything in a longitudinal mode, to do any analysis which is spread out over a significant period of time, because during that period it's almost inevitable that reporting zones will have changed. This seems to me to be a major impediment to succes in social science. I think it's unfortunate that we seem to be going in the wrong direction at the present time. If you look at the market forces which are driving social data, they come from such areas as retailing where the need to use constant reporting zones is relatively insignificant. What is much more significant is the need to relate reporting zones to applications. So there's been a disturbing trend in recent years towards using zip code boundaries as reporting zones which have much poorer quality control than any of the zones that the census regularly uses.

The third element is time, and I think it is a sad reflection on the GIS field that we have so few ways of dealing with time as a dimension. We are used to a system of data collection represented by the Census and other agencies which faces the same problem of dealing with time dependence. An item that ought to be on the GIS research agenda is the potential for doing analysis in a continuous manner. We are so used to data arriving in discrete chunks, but a surprising number of different types of data are now available on a semi-continuous basis. I'm thinking of such things as emergency planning data, and records of fire emergencies and ambulance emergencies. Many health statistics are available at the highly desegregated, almost continuous level. What this suggests is the development of an associated set of techniques for continuously testing hypotheses about time-dependent data, and there are example applications in identifying hot spots in emergency planning. These are well within the capabilities of GISs, but I think we're constrained by current thinking not to follow that kind of line.

The fourth area is the user interface, and it seems quite clear that if the GIS field is to be successful it has to think very carefully about the user interface which is presented. As more and more sophisticated forms of analysis come along and are

demanded by users, it becomes more and more important to think very carefully about how the system interacts with the user.

Here again, we seem to be very constrained by historical ways of thinking. We're very constrained, for example, by the map model. We think in terms of map primitives, and yet in many ways that acts against developing the true potential of GISs. For example, a map makes it very difficult to display such things as flows or fuzziness or time dependency, all of which are very appropriate ways of displaying spatial data. We are very much limited by the constraints that have been placed historically through the use of the pen. Even in translating to computer systems when we moved from the pen to the plotter, we maintained those constraints, although they are obviously not true of the visual display unit which has no such need to regard things as clear boundaries and strokes of the pen.

One of the areas of potential that I think may well develop very rapidly is scene generation. There is no longer a need to display data restricted by the abstract formalism of map primitives. We can instead think about simulating the way the scene would actually look. There are obvious applications in landscape architecture and in other areas where it's useful to visualize what the world would look like. I'm working with someone in the area of long-term climatic change where it becomes very important to simulate the way the world would look under certain climatic scenarios.

Some of the tools that are necessary in that area are coming along quite quickly. We can already simulate terrain using random stochastic processes very successfully. We have methods of simulating trees, and we can produce something that looks like an aspen or a spruce at will. This is an area where we can really begin to exploit some of the potential of GIS technology.

The final area is the social institutional one, and David Rhind has covered this already and referred to legal implications and confidentiality. I'd just like to add one point about the need for research in system evaluation. One of the areas of GISs that geographers in particular can do successful research on is system benchmarking, including methods of estimating the workload that a system has to handle, and in particular coming to grips with the enormous set of functions that seem to be required of GISs. What we need is some method of organizing the kinds of functions that GISs are being asked to perform, and identifying the limits of the set.

So if I could quickly sum up, I think that the area that has to me the most excitement in GIS research is the development of products which are not constrained by map technology. We've grown up with the map, and the map has been the enabling medium for development of GISs, but I think we're getting to the point where the real potential of GISs is almost constrained by maps, that to get to things like real time decision making and the

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kinds of products from a GIS which really exploit its technologies, such as animation and scene generation, we need to get away from the map model. And that applies to the data structures which are used, which essentially reflect maps and don't allow us to account for things like fuzziness which again are not consistent with the map world.

All of these things are easy to say, and they're very hard to do, and one of the essential issues in discussing the scientific agenda is the institutional and organizational arrangements that will make this research come about.

I think there is a very distinct difference between the academic and the agency views of the GIS research agenda, and I'd like just to identify two areas of difference. Both are driven by the same forces, and both have to respect the fact that most of what we currently regard as GISs has been application driven. What the academic scientific agenda can contribute, I think, is a much stronger sense of the underpinnings, the theory and philosophy which lie behind GISs, the kinds of organizing principles on which GISs can be discussed and developed. The academic community has the time to take a longer term perspective and doesn't have to respond to the same immediate needs.

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PLENARY SESSION 3. TRENDS IN HARDWARE AND SOFTWARE FOR GEOGRAPHIC INFORMATION SYSTEMS

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PLENARY SESSION 3
TRENDS IN HARDWARE AND SOFTWARE FOR GIS

CHAIR: Michael Dobson, Rand McNally & Company

PANEL: Jim Meadlock, Intergraph Corporation
Jack Dangermond, Environmental Systems Research Institute
John Lange, IBM Corporation
John Estes, University of California/Santa Barbara

Michael Dobson:

On the screen is a new Rand McNally product called a Street Finder (TM). It's an augmented city map cut up into booklet form. This is an example of Detroit and the three counties surrounding Detroit. It is entirely digital, and the graphics were done entirely on an Intergraph system. It is a beautiful product. As a matter of fact, I showed it to Sandy McNally who owns the company, and he said, "Wow, that looks like a Rand McNally map." And one of my employees said, "Imagine all that money to make a Rand McNally map."

The second slide shows a portion of the index for this product. The index for this particular application was a result of writing a significant amount of software that passes Intergraph graphic files to Arc Info. We used the polygonal boundaries for these to create cookie cutters which pass through the graphic files and remove all of the graphics names, and we create our index and the bingo key, the page, the town, the place, the populations, using Arc Info.

Mapmaking requires capabilities that currently transcend the needs of any single system and generate a situation that often requires several complementary systems.

I think trends in allowing Rand McNally or any other vendor to have one system that will meet all these needs is what we're going to hear about today.

It is desirable, however, to support and maintain "single" systems and our panel today will be directed towards future trends in GIS hardware and software.

The Hardware Trends. Jim Meadlock:

I'm supposed to talk today about hardware trends. That tends to be, I think, for this particular group, something about which you probably have a gross knowledge and probably aren't very interested beyond that level. I think in particular that hardware has outpaced the development of software, and I think the real thread that ties together your interests is software.

Nevertheless, let me try to put in perspective the hardware

trend as I think it relates to your interests. In other words, let's look at the environment in which you are interested in hardware. That environment is composed of fundamentally four things that interest this group.

First of all, there's a very high rate of change in the digital technology that's driving the core products. I don't know of any other effort in which we're associated day to day where the rate of change is as great as in the digital business, except maybe the stock market. At least in our business, it's a trend that's in our favor, and with the stock market, it's your guess today.

The second environment that we have to look into as we look at the hardware is that we're entering an era where very large volumes of data are of interest. I think if we look back over the last 50 years or so, there's been a gradual accumulation of data that is of interest to a group like this, and now suddenly it's as if the gates were opened and there's data from everywhere. The U.S. commercial satellites and now the French SPOT satellite are going to inundate us with very good data.

The third issue in hardware in terms of the environment I'd like to address is that the users are now more sophisticated. I only need to look at a young son I have and realize that at the age of eight he probably knows more about a computer system than I knew when I graduated from college. And so what we're looking into is a set of users who are rather sophisticated, a set of users who assume that a computer is going to be accessible to each of them and that it has the tools to do what they want to do. In other words, those things that you have spent your life creating--a map, a Rand McNally map--a guy graduating from school today believes he has a computer that can quickly take a set of digital data and change that map and produce another map. The things that we've agonized over for years should now become rather easy to do, and that's what the user expects. Now those of you who have gone out and had software done especially for your project might argue with the fact that it's now easy. I can only say that all software programs ultimately work, or else they are retired and its said that they worked. I think we've all been a part of one of these in our lives. Hopefully, we've been part of the former most of our time.

And then the fourth environment is that of many casual users. If we go back in our history, people wanted to thumb through a library of maps to find something. In the future, they want to sit down at some device and access who owns this parcel.

So we have in the environment we want to look into a changing technology that is indeed impressive. We have the availability of very large volumes of very useful data, very useful and, hopefully, very cheap soon. And we have both sophisticated and casual users that want to share the capabilities that this hardware system brings to t

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So let's talk about the hardware trends to support that environment. I really want to talk about putting the hardware in perspective. The day of the stand-alone island for accomplishing a sophisticated task is virtually dead in that even the most elementary systems that people are looking at using today--a personal computer-type of system--the in-thing to do now is to network that system. So what we're really talking about is hardware capabilities that permit the user to have access to other things when he wishes to.

Let's talk a minute about the computing power that drives that. This particular slide indicates a product that is the core product of the computers and work stations that we currently build. It's something we call a "Clipper module," basically five millions of operations per second. If you go back to when I began in this business, you would not have believed that possible. You will see going into next year that we and a few other people are announcing products that are going to double and triple that capability with the same real estate. And so what you're seeing are capabilities in digital processing that are available at your desk that are going to be far more capable in terms of basic manipulation of data than were systems that were in the largest computer rooms five years ago.

That basic trend is changing the industry and changing the perception of how you distribute hardware. It is changing the perception of how you develop software to take advantage of the capabilities that are going to be available at a very cheap price.

Secondly, the large data--you're finding that the disk systems are basically doubling in capacity every year. VAX space products are now beginning to serve as basic database accumulation facilities. I think the thing that will influence your business most in terms of storage capacity in the next year is the optical disk. You're going to find that optical disks are becoming a standard in the industry for archiving the very large volumes of data that are becoming available to you. You'll also find the CD ROMs beginning to be a way of distributing data from core agencies that have data that must be used or can be used by a large number of you who are interested in basic map data.

One way or another the optical disk in 1988 will be probably the most important storage media for distribution of and for archiving of data that's relevant to your interests.

The cost per bid is terribly aggressive. The reliability is outstanding. There are still software problems so that it is difficult to find what you want with the optical disk.

Thirdly, I'd like to talk about networks because in everything that you design in the hardware business these days, you must worry about the network. Again, there are no stand-

alone islands in the future. There are only windows into a network, and that network will have available resources that are database resources. It will have available computer nodes for very complex calculations. It will have available plotters to give you a hard copy. It will have available scanners to scan in things that aren't already in digital form. And in general, it's the backbone of the information network that must be accessible as this industry progresses.

Everything will be on the network. Every design of a hardware component that one wishes to do today must be based on a network resource. And you will begin to see this in all the offerings of all the vendors.

The point I want to make is that networking is now beginning to evolve standards. They're beginning to evolve standards by which different vendors can have access across the network so that procuring a system does not force a buyer to buy subsequent products from that same vendor. Now obviously if we as a vendor sell you that first system, we'd love to have you buy the rest of that system from us. But the reality of the world is you can't sell in today's marketplace unless you adhere to the standards that are emerging in the world, and the standards that are emerging in the world ensure that a buyer of products can buy different pieces from different vendors.

If you look at those standards--I think Ethernet is evolving or has evolved as the standard for transmitting data. There are other standards. Both Ethernet and Token will run under the ISO standards that are evolving, but if you look at today's world, Ethernet is pretty well winning that war in my opinion.

TCPIP is the standard right now by which most workstations communicate. It's the protocol on top of Ethernet. ISO will become the dominant standard. There are still some things undefined in ISO, but it will become the dominant standard.

I think NFS, which is a distributed file system as defined and sold by SUN Microsystems, has pretty well won the war on how one does a distributed file system. And those of you who only want to worry about GISs say, "What do I want to worry about a distributed file system for?" In reality, you're going to have workstations and personal computers that don't have enough storage to access the files that you wish to access. They will be on a different node. Therefore, it will be terribly important to you in the future that you be able to access those files as if they were on your particular node, and therefore some sort of distributive file system is essential to give you the capability that you would like at your window into that network.

Let's talk about workstations then. I could say PCs, but I come from a workstation world. We don't build PCs, and so I'll not mention them again in this discussion, but I do acknowledge the fact that they exist and that most of you, one way or

another, have access to or use one. I think you're also going to see, however, that the price differential between the high-end personal computers and the low-end workstations begin to disappear. It's going to be increasingly difficult as we look into the next two years to know the difference between the PCs that have graphics and the workstations from a functionality and a price/performance point of view. I think you're seeing that difference begin to be eroded, and so I will use the generic term here of a "user window" and understand that it may be a workstation or it may be a personal computer.

This happens to be a range of workstations we offer. Each user will require a different kind of capability in the future. There will be those people who only want to access the alphanumeric data. That's obviously a rather inexpensive window into that network database. There will be other users who will wish to retrieve a basic map. Obviously, that requires a degree of graphics capability at that window. And then there will be others who will want to create and manipulate in a rather dynamic fashion large volumes of data, and that will require an increasingly capable window into the database.

So there are going to be all kinds of workstations that are available for usage. If you look across an organization in the next five years, everyone doing a useful job will have some kind of window into that network and database. The type of window used will depend on the type of work to be done--whether it has a lot of computation capability, whether it has graphics capability.

If you look at the standards evolving in that world, in the workstation world, UNIX is the dominate operating system standard. If you look in the PC world, it's MS DOS, PC DOS, and the next generation products that IBM and Microsoft have announced.

So the one clash that is going to differentiate the personal computers from the workstations is that I think the workstations will have UNIX as their dominant operating system. I think they will have some version of the personal computing operating system working in a window under that, accessible so that you can use both at the same window. I think in the personal computer world, it will probably be purely the MS DOS or follow-on to that operating system that will be available.

The standards are evolving there also. GKS is a graphics description language; X-Windows is a common user interface by which application programs can be forded. Again, it may not really matter when you look into the future from whom you buy that hardware platform. The fundamental standards will have to be supported in order for that vendor to sell a product, and therefore software should be moveable with reasonable ease from one platform to another. And certainly all products should be able to be accessible across that network.

These are just examples of the workstations that support that. I think the primary window that you will use, however, will be a window that's a single-screen product that gives you access across that network. I would be remiss in not admitting that hardware is really getting less important as you look into the future. It's getting cheaper and better. It's the software that makes the difference.

And the one other point I would like to make is that the next generation of software has at its disposal very high-speed processing platforms. And, therefore, the organizational structure of that software is able to do things differently. If you look at the products that we offer in the GIS marketplace, they're now object-based, which is a more sophisticated mechanism for defining the structure within the database. And that's only really practical because of the computational power to manipulate that is now available in this generation of workstations.

TRENDS IN GEOGRAPHIC INFORMATION SYSTEMS SOFTWARE

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ABSTRACT

This paper first notes the influence of hardware developments on software trends and then considers what some of these influences have been. Next, Data Base Management Systems (DBMS's) for tabular and cartographic data are discussed, and the notion of using a fourth generation language for managing GIS data is considered. Problems of system integration, creating viable hardware/software systems, and the need for GIS's to interface to many types of DBMS's are then taken up, followed by a consideration of the "toolbox approach" to GIS design. Then a series of areas in which early improvement in GIS technology is expected are taken up; these include: cartographic products, 3-D displays, interfaces to other technologies, user interfaces, map compilation and integration, modeling, user training and user support. Some other technologies (parallel processing and artificial intelligence) which might have application to GIS are briefly discussed, and then the paper concludes with two suggestions: that diversification of GIS use will rapidly occur, and that perspective is needed during this period of rapid change in GIS technology.

1. IMPORTANCE OF HARDWARE INFLUENCES ON SOFTWARE TRENDS

It is difficult to begin any discussion of software trends except in the context of the present trends in hardware development. These trends include the rapid increases in computer speed and power, the rapid fall in costs, the diversification of hardware devices available, increase in available memory and speed of access, the trend toward networking and rapid transmission of data between nodes, increase in the quality of display devices, graphic independence and so on.

2. SOME EFFECTS ON GIS TECHNOLOGY OF IMPROVEMENTS IN OTHER TECHNOLOGY

As hardware becomes faster and operating systems more powerful, we are likely to see the development of generic, machine-independent software tools in which more emphasis is placed on functionality than on optimization for speed. It will also become easier to make use of more generalized fourth generation languages. And it will be possible to have high quality GIS's with greater flexibility and greater ability to support ad hoc application programming. Similarly, relational databases will become more practical because they will function more rapidly in the new machine environments.

The development of powerful workstations and of personal computers are particularly important to the present course of GIS software development; more and more GIS data bases and applications will operate in a network environment in which workstations are prominent. This means software will have to be developed with a distributed system environment in mind.

3. DATA BASE MANAGEMENT SYSTEMS (DBMS'S)

It is important to recognize that there are fundamental differences between managing tabular data and map data. Present DBMS technology is very good for managing tabular data (adding, deleting or modifying records), but mapping involves much more than just the storage and retrieval of data. DBMS technology is not very effective for updating and managing cartographic data, except the attribute data associated with spatial features. This is so because of the topological relationships between map features. When, for example, a land parcel's polygon is adjusted, the relations of surrounding parcels to the first parcel and to each other must also be adjusted; the geometric attributes of all these parcels change. Thus manipulating spatial data is much more complex than managing tabular data. It is also ESRI's experience that geographic information is updated in a way quite different from the updating of tabular data. To update maps, users "check out" maps from a library, update them, review the updates with an administrator and then reinsert the changed data. To do these things effectively, software tools are needed which are focused on the special way in which maps are handled.

4. TABULAR DBMS'S

Tabular DBMS's are an effective means of managing the attribute data associated with the spatial features of maps. At present there is movement toward more open architectures for such tabular DBMS's and away from some of the more structured approaches. This often means movement toward relational DBMS models, using an SQL style of interfacing to users.

Object-oriented database structures are being proposed for tabular DBMS's, usually as a means of avoiding some of the limitations of relational databases for specific applications. At ESRI we believe that object-oriented structures are not as useful as relational ones, especially when dealing with geographic phenomena. While it may be reasonable to use an object-oriented approach in dealing with architectural features, such as doors or windows, we question using this approach in dealing with natural features such as hills, streams, geologic formations, and so on. Object-oriented DBMS's have the additional problem of often embedding proprietary data structures in the database, thus inhibiting data exchange and later use. In ESRI's ARC/INFO we have adopted a special data handling approach, similar in its philosophy to an object-oriented DBMS, but adhering to a relational architecture so that data can be related, joined and expanded easily.

5. GIS DATA MANAGEMENT: DATABASE MANAGEMENT SYSTEM OR FOURTH GENERATION LANGUAGE?

At present there are two approaches to managing cartographic data in a GIS. One is the DBMS approach, in which the DBMS serves as a utility for application programming. Using the DBMS, application programmers go through a very structured design process to build an application. The resulting program is intended to allow many users to simultaneously access the database quickly and efficiently, while maintaining data integrity; but this usually is accomplished at the expense of ad hoc query capabilities: often such queries are not permitted at all. Nevertheless, this is a sound approach for working with static databases and for databases which aren't used for sophisticated application programming.

The other approach is the use of a fourth generation language. Here the idea is to build a set of procedures, tools, commands, and report writers that make it easier for end users (or people supporting them) to develop their own applications on an ad hoc basis. This is the approach that we have taken with ESRI's ARC/INFO for example.

Unfortunately, for those selecting a GIS system, it is often difficult to determine which of these two approaches has been taken in a system's design and what the actual capabilities of a particular software system are. This is true even during actual demonstrations, because the applications demonstrated have almost always been programmed in advance.

6. GIS DATA MANAGEMENT TRENDS

GIS databases are now being designed for transactional updating, for the storage of data with minimum redundancy, and to permit the generation of views-on-the-fly without requiring much previous application programming. Another trend is toward avoiding the use of graphic storage. Instead graphic primitives are stored; these are then associated with one another to produce the graphic view of the database on-the-fly in response to user queries. Although this a slower approach, hardware, as indicated above, is making it increasing practical.

7. PROBLEM OF SYSTEM INTEGRATION

In designing a GIS it's important to recognize that the goal is to create a system that works for the user. Unfortunately, one cannot create such a GIS system, or any optimal system, simply by choosing the best available parts. It is not possible, for example, to create an optimal system, or even one that works, just by choosing the fastest processor, connecting it to the largest disk drives, putting in the "best" operating system, and then using the most complete databases with the most powerful GIS software. Any time a system is created it is the system as a whole that must be optimized. This means that in choosing parts of the system one has to be concerned

with carefully crafting the interfaces between the component parts. The process of integrating such components is a whole problem in itself. To do the system integration effectively probably requires experts who understand how such integration should take place and how to make it happen. It's also important to recognize that beyond integration of hardware with hardware, there is the problem of integrating different data sets. Not every kind of data can be overlaid on every other. Not enough users recognize this.

What is really needed is more consideration of these problems when standards are being set for the industry, when system vendors are designing GIS's and when users go shopping for this technology. Otherwise vendors are going to create, and users are going to suffer from, excessively high expectations about what is possible or workable.

8. HARDWARE/SOFTWARE SYSTEMS FOR GIS'S

One of the reasons we at ESRI feel the above problems so keenly is that we see the market demanding compatibility between an ever wider variety of hardware and software, even while some vendors have taken the approach of putting their GIS software on only a single type of hardware. Often, for a variety of reasons, individual users are committed to a particular hardware vendor. For this reason we have found it necessary to put our GIS software onto an increasingly diverse set of hardware devices. There is, inevitably, some cost to such an approach: we engineer our software especially with adaptation to new hardware environments always in mind. But this approach permits taking advantage of the large hardware vendors' investments in making the best machines possible, permits users to keep up with the rapid developments in hardware, and permits systems designers to choose lowest cost/most effective solutions. We think this trend is a permanent one in the industry, driven by the success of diverse vendors in meeting user's needs for good hardware.

9. NEED FOR GIS SOFTWARE TO INTERFACE TO MULTIPLE DBMS TYPES

Similarly, we have found it necessary to move beyond the support of a single type of DBMS for attribute data, to

support of and interfacing with many kinds. Our experience is that optimizing for differing applications often demands differing DBMS's. Other factors may also determine the DBMS choice. Users may have had their own reasons for selecting the DBMS they already use, may have a considerable investment in their DBMS, and data conversion to any other DBMS may be a considerable problem. In such cases asking users to accept a change is usually not a viable option. For all these reasons we think it is best to make available a set of software tools that allow users to adapt our GIS software to their DBMS. We think this is a strong trend and will continue to be so in the future.

10. GIS SOFTWARE: TOOLBOX APPROACH VS. SPECIFIC APPLICATION APPROACH

In the past, GIS users have concentrated on building specific applications of computing, particularly when they were working in mainframe computing environments. In these cases a lot of care was devoted to defining at the outset exactly what the user needed and wanted and then providing that to the user in the most effective way. With the introduction of DBMS tools, however, this approach became less important. Fourth generation languages, such as query languages, made it much easier to generate applications on-the-fly, or modify existing applications to meet some new need. With command languages, "spatial report writers" and the like available, the writing of macro's for specific purposes became something that the users could do for themselves in most cases. Some of these macros might be worth saving and polishing; others could be discarded after use because the investment in writing the application was so small. We think this second approach to writing applications represents the dominant trend now and in the foreseeable future.

11. AREAS OF EARLY IMPROVEMENT IN GIS TECHNOLOGY

There are a series of GIS functional areas in which early and rapid improvement in functionality are to be expected.

11.1. Cartographic Products

Cartographic products continue to be of primary interest to a great many users. For this reason, and because the

technology can support the needed developments, continued improvement in this area is certain. We can expect to see the availability of more projection transformations, better symbology, better interfaces to even more diverse output devices, better integration with complete production systems, and so on. Given these developments, more and more of the major map producers are going to go to GIS technology for their production work, often in preference to CAD approaches.

11.2. 3-D Displays

The capability of GIS's to efficiently store and analyze elevation data and to produce useful 3-D views of these data is emerging at the present time. Because of this development and the usefulness of such views of elevation data, further rapid advances in this area can be expected. The ability to display cartographic coverages on top of 3-D models will come next. Later we should be able to more readily combine architectural data with natural resources databases, permitting more effective display of a built environment on the landscape.

11.3. Strengthening of Interfaces to Other Technology

Related to the above is a more general trend. For example, rather than GIS technology supplanting CAD technology, or the reverse, it seems likely that the interfaces between these and other GIS-related technologies (like remote sensing, image processing, architectural graphics, etc.) will become stronger and better defined. This may occur because we learn how to better structure GIS databases so they can support applications beyond the immediate GIS field. It may be, for example, that putting parametrics data, such as splines, into geographic feature data, or putting elevation information in at each node, might make the data more accessible and useful to a CAD system. Such approaches may become more common and may promote closer coupling of these diverse technologies. To accomplish this what we need is a clearer understanding of what data structures are most suitable to each kind of situation and use. This is an area in which we are making some progress.

11.4. User Interface

One of the chief effects of having more powerful computers, workstations and operating systems will be the development of more sophisticated, flexible and well managed user interfaces. With more and more GIS users previously exposed to the very effective graphic interfaces of computers like the Macintosh, there is a growing expectation that GIS user interfaces should be equally easy to use. This expectation will be met in the years just ahead.

11.5. Map Compilation and Integration

With more people wanting to use GIS technology in working with their spatial data, and with more and more data becoming available in the form of images, recently automated databases, etc., there is increasing pressure to develop automated means of compiling maps and integrating various kinds of mapped data. At present, much of this must be done by manual means . The tools needed include rubbersheeting, conflation, superposition of imagery and graphics, etc. We can expect in the near future to see the development of hardware to support these functions; the associated software will come soon afterward. Probably a workstation, especially designed for map compilation and integration, will be the result.

11.6. Modeling

GIS technology is increasingly being applied to the solution of major human problems. These problems include our treatment of natural resources, our need to produce adequate food and living space for a growing human population, the need to reduce pollution, etc. Many of these problems are very complex and deal with even more complex natural and human-made systems. One powerful tool in dealing with these problems is the use of modeling, in particular the use of systems models coupled to GIS's. It may be, indeed, that such an approach represents the most cost effective way of analyzing and then making decisions about the most pressing problems of our time. For these reasons we can expect to see the emergence, in the near to middle term, of a whole new field built around the Geographic Information Modeling System (GIMS). Tools for such a system are being created at the present time.

11.7. User Training

While the concepts on which GIS technology rests are likely to grow more complex, it is likely that training users in this technology will grow easier. The means for training, including the newest technologies for combining images with text or with videotaped presentations, promise effective GIS user training at falling costs. Nevertheless, it is essential that the fundamentals on which the use of GIS technology is based-- how to gather data, how to store it, how to use it-- should continue to be well taught at universities and colleges.

11.8. User Support

If poor support of software has ever been acceptable to users, it is certainly becoming less so today. Increasingly users are impatient with software which requires any support from the vendor. Having learned computing on personal computers for which little or no support was provided or needed, users expect GIS software to function the same way. Given the powerful tools becoming available to GIS programmers and systems developers, it is possible that we shall move a long way in this direction: systems so simple and logical that little or no additional support to users will be needed.

12. OTHER NEW TECHNOLOGIES WITH POSSIBLE APPLICATIONS TO GIS'S

There are a few technologies which are part of the computer science field which are often mentioned as having possible future applications to the GIS area. These include, perhaps most prominently, parallel processing computers and artificial intelligence/expert systems.

12.1. Parallel Processing

While parallel processing may have great utility in dealing with the problem of image processing, it has far less utility in dealing with mapped data. In processing images there can be considerable parallelizing of the processing effort: every pixel could, in principle, be dealt with by its own processor. But mapped data in vector form does not

lend itself to such parallelizing. Map processing by GIS's tends to be very I/O intensive and requires a great deal of computational time for differing sets of data (matrices, arrays, etc.). For these reasons parallel processing is likely to find more application in dealing with source data rather than in GIS processing itself.

12.2. Artificial Intelligence

Application of artificial intelligence or expert systems to the GIS field has been slow in coming. While some applications in the emergency field have been worked on (e.g., rapidly providing directions to emergency support in the case of earthquake, wildfire, flood, or the like), most GIS-related work is really still in the research stage. Because of the expected generality of the capabilities of artificial intelligence, it may be that it will turn out to be like GIS technology itself: used in an ever widening range of applications. But in the near term such uses are not likely to go beyond early development efforts.

13. SOME CONCLUDING REMARKS

There are two final areas about which some comment should be made.

13.1. Possible Rapid Diversification of GIS Uses

This conference is centered on the topic of GIS's, a centering that makes good sense to those of us attending. Yet no similar conference on "computer graphics" is likely to be held, simply because it is recognized that computer graphics has become a field so diverse and growing so rapidly that no coherent picture of it could be captured by a small group of specialists. Similarly, within a few years it may be that the use of GIS technology will have grown so much and spread to so many fields that it will have forever gotten beyond the grasp of the specialists who helped create it. Perhaps we can look forward to that day within our lifetimes.

13.2. Need for Perspective During a Period of Rapid Change in GIS Technology

Perhaps the developments just hinted at are signs of our times in this field. There are other indications of just how rapid changes are. There are many announcements of new developments in hardware and software, some of which are premature, some of which never come to be at all. There is an explosion of buzz words-- jargon-- in the field; some of it has meaning and importance, some of it has neither. Many users and potential users suffer from illusions that each new technical development can shortly become a part of their systems.
All these things have led to confusion and disappointment for users and vendors alike.

At such a time it seems important to maintain an historical perspective on the developments in the GIS field; to read current events with past history in mind. This provides at least some antidote to either overwhelming optimism about the future or to pessimism about it.

And, when so many claims are being made and so much is being promised, it is a time when the prudent ought to demand rigorous proof of claims; proof that depends on testing under the most realistic conditions possible.

There are a lot of databases out there with lots of different people using them. But when you look at the databases, one basic problem is evident. Jack referred to it as referential integrity; I refer to is as who's got the correct copy. When you have workstations that have high capacity fixed disks and 50 MID ratings, tremendous amounts of storage processing power, who's going to manage that? Traditionally, the data processing guy used to. Now he's going away per se. We're starting to handle these things locally, but if all of my users start that volume and I start shipping things across the network, the hardest thing for you to find is the correct copy.

And, in fact, the information that we have is that 60 to 80 percent of your highest paid professional's time is spent getting to the correct copy of the data. That says we've got a tremendous capability to enhance productivity by getting people to the correct copy. So that's the first thing I need to do the job.

The second thing that I need is a handle on what's going to happen in the future. And I'm speaking from a planning perspective. I'm an urban planner by trade and a geographer, and computer systems are things that I don't like dealing with. It may sound odd for a person who works for the company that I work for. But my career objective with IBM is not to program, and I think most of the geographers and the urban planners don't want to deal with that end of it either. But we need solutions--better tools. So if I can get to what exists and what's planned, then at least I'll be working with correct data. IBM's GDBS product is just that--an interface to the database that will show me who else is working on the thing that I'm working on and what work is planned for the near future. And why do we need that? Well, from a municipal standpoint, have you ever seen a local municipality repave a street and then next week the utility company comes in and digs up that street to replace its lines? This indicates separate databases for separate purposes--no means of merging those two together. So without that, we can have all the networks and all the software solutions. What we need is mechanisms for managing them.

And again, you'll see from the existing database there are user exits tying in other databases. Within the Graphics Program Generator (GPG), our GIS software, there are exits to access other sets of data outside the central database. Again, from the distributive environment, all of those different databases may exist in a variety of different locations and formats.

So this is currently what IBM offers. I don't want to go into any more detail than that. What I do want to show you is a product direction that acknowledges that the applications people need better tools. And I think you heard the word tools--

enhancing the interfaces, better tool kits, going to a variety of different databases, both IBM and non-IBM. So that's really the challenge that faces us.

Based upon all the things that you've heard, where do we go from here? What are the things that we should be concerned with? What does the future hold for us?

There are some basic trends that we'll talk about in greater detail: tremendously greater computer power to the individual, and cost--the costs of computers are going down. The cost of computing is going down. We have data-driven models. What do I mean by data-driven? It's not enough to be able to look at the parcel. The planning commission needs to know that when I allow a development on that parcel I have sufficient school seats, fire protection, potable water supply, sanitary sewage capability, all tied into a model. As I approve each one, I get an interactive model, not just the pictures, not just the data, an integration of those into models.

We're going to talk about some new ways of doing business and some changes in the work force. Greater computing power of the individual--the thing that's driving it is technology. We've got faster, more dense chips and logic, more power at the workstation level, and tremendous growth in personal computers.

I represent a group in IBM called Public Sector Industry Marketing. Sixty percent of all the PCs that IBM has sold belong to my customers. That's an awful lot of PCs. That's an awful lot of local power. How are you going to connect all of those to share the resources? And if you've got tremendous amounts of storage there, who is doing the backup on those? Who is allowing someone else to access that information? Who's got the correct copy. So, although the networking seems like a nice solution, it's going to cause a whole series of other problems. I'm going to be able to run a lot of those host-based programs locally. And that's going to give access and requirements for more data locally because I was going to this big corporate or big departmental database, and I'm going to have to handle those things down there (at the workstation).

Now in terms of cost, costs of hardware have gone down tremendously. The cost of software has pretty much stayed the same. We've seen some fluctuations up and down, but it looks like it's going to be pretty stable. The cost of a GIS, of getting your data in the right format, of conversion, is running at somewhere in the range of 70 to 75 percent of the total project cost. What this is saying is that hardware and software are going to be nits in terms of the overall cost. In the future, people will not be able to afford systems unless they can get the data into the system less expensively. That's the biggest challenge you have facing you in a GIS. So we've got to reverse the trend of escalating conversion costs.

There are new ways of doing business; decisions based upon complete information; giving the planner access to all the pieces of information that he needs from databases that he doesn't maintain through networking; and best utilization of existing resources. Cost avoidance--don't put the capital cost into building the new police station if I can solve it by adding a connector route or by districting. There are things that we're not very good at as planners and geographers. Little pieces of it you see now, putting a whole picture together in a total growth management scenario just isn't there yet. But there's no reason why it can't be there.

There are environmental impact analyses, the what-if scenarios, the true planning models; less time spent collecting, correcting, and editing the information. Traditionally, if a planner wants to find out all the single family homes that sold in a certain time period within a certain price range within a certain district, he'd have to go and extract that information manually and that's a very time-consuming process. Spending less time getting the information instead of getting a whole list of all the properties and extracting them manually, we see the return on investment in GIS technologies. We see the spatial analysis allowing us to do that. But we're going to see more and more requirements in that area.

As we get to do more things locally, we're starting to look at the very foundations of our business. I work in Poughkeepsie. I live in Poughkeepsie. My manager sits in Bethesda, Maryland. I don't have to live where I work. Working off hours--when we didn't have the PCs and the networking, we had to go back to the office at night. We wasted the time traveling home and back to the office. Now we can just dial in and start doing the work. It gets to the point where you say, "Do I physically need an office?" And there are people within IBM now who don't have an office. They work at home. Think of the impact on office space requirements. We are getting increased productivity because we can do the things we want to when we want to do them.

Let me make a prediction. We've got the mainframe on the desk. You're seeing very large-scale processors. You're going to see more of that. But that's going to drive more data. To do the things that we aren't doing now, it's going to drive more complex models, and it's going to drive the individuals who are maintaining that data crazy unless they've got some series of standards to back up that 50 meg database that they've got inside their PC. Disk crashes happen occasionally, very randomly, but when they do, you know it's Murphy's Law. And when you've got 50 of those 50 MIP machines, you're only compounding that problem and getting the information from here and pulling in a piece of 50 of those 50 here into your own workstation is another set of problems.

So one of the things that I am predicting is an evolutionary role of the mainframe. The more things that we have at the local

level, the more things that we're dealing with, the more we will require someone to manage that. And the central place has always been the place where that sort of a database is managed. So, while I would say that you'll see great increases in the number of local processing units, eventually that will drive people back to a mainframe environment.

Evolving working conditions--we talked about that a little bit. There is a division of creators and users. The tools we have are getting better. I wouldn't say that any of them are really user friendly. The best macro languages still require the end user to memorize somewhere between 200 and 1,000 commands. That to me is not user friendly. What I want to be able to do when I do an ad hoc query is fill-in the blanks and let the machine go out and get what I want. We're not there yet. So you're going to see better tools to do that.

You're going to see better input devices--intelligent scanners--there's a lot of work being done on that. But you've got different graphic standards. You've got different graphic capabilities. You have different types of models, and somehow that has to evolve to make all these things work together. And the end result of all that is to enhance our productivity and our decision making both tactically and strategically.

You are the people who are going to be making the decisions about what systems you're going to use, I just want you to keep these things in mind, because it all sounds great. The future is almost here, but we really are just beginning to understand the problems that the future is going to bring us.

Michael Dobson:

I often marvel at the expertise that speakers such as these bring to the stage, and I also wonder why a lot of the questions that I have never seem to get answered. My questions aren't really very difficult, but when we hear that software costs are going down and efficiency is going up, that hardware costs are going down and efficiency is going up, as a producer of maps on machines, I often wonder why my costs are so high. And I often wonder why if software is becoming friendlier, every time I buy a machine, I buy a new programmer; and if it's a different machine, I may buy a new systems person, and then I may buy someone to rewrite the programs because they don't do what I thought they did in the first place. It is all getting cheaper, but at least in terms of my company, that cheapness is costing me a fortune.

And I'm not quite sure how to deal with that because in industry as well as municipalities and government, you are constantly having more and more data available to you, as Rand McNally is, and you have more and more processing power. You've got a mainframe on your desk, and you still don't seem to be

getting the product out. You still aren't solving the problems that you want to. I'm still not producing the maps that I want to, and in many cases, a number of us are beginning to generate our own systems and our own software because a lot of us have really simple tasks, and we now have the knowledge, and there are people out there who have the knowledge of how to build small, efficient systems for very singular-minded tasks.

But there are very few systems available commercially for simple tasks, and I would contend that straight-forward mapping is about as simple as you're going to get in graphics. We may want to put a big database on it. We may not want to put a big database on it, but I am concerned that in looking for the future and all of the glories of Artificial Intelligence and looking at the glories of 50- and 100-MIPS machines sitting on your desk, that we have lost sight of the fact that we do want to process data, that we want to create products. We want to create them in an economic, timely, and efficient fashion. And while there is no one more than I who has the sin of loving high tech and loving complicated software and being able to solve every potential problem that any user might ever think of, it may be that one of the greatest problems of systems that we have created is that we try to solve all the potential problems and miss the fairly simple ones.

Summary. **Jack Estes:**

Basically, what we're seeing in geographic information systems, is the price performance of hardware essentially doubling each year. We're currently seeing an increase in efficiency of software on the order of about 20 percent per year. Actually, hardware is currently outstripping the ability of software to keep up. Having said this, let me make a few specific comments on what the speakers said, and then I will attempt to summarize very rapidly.

I like what was said by John Lange that in geographic information systems we need an evolutionary approach to get to where we're going. Jack Dangermond indicated on one of his slides that we need to take a historic approach to the development of geographic information systems. We need to learn from the past. People who do not learn from the past are doomed to repeat the lessons we should have learned from history. This is all very well and good. But let me ask you a fundamental question.

How many of you have seen one single text book or article that presents a coherent history of the development of geographic information systems? I'd like to challenge you on this because I've been trying to find one. I and my coauthor, Dr. Jeffrey Star, have been trying to put a historical development section together in our forthcoming text. We are currently having to

research and assemble this piece by piece, and it is an extremely difficult task. GIS development has occurred along many different lines. It's going in many different directions. This is a strength and also a glaring weakness in the field. There is a lack of focus.

We, as researchers and applications-oriented practitioners, should realize, if you want to go far enough back, that we started with manual systems. We're now moving into the digital world. Jack also talked about the need for rigorous testing of claims with respect to the current levels of systems performance of these new systems in this field. I think this is very true.

Jim talked about the future of the systems we're using and the large amount of data we're going to have to be processing in the future. He talked about Landsat and SPOT data. Right now, as a visiting senior scientist with NASA, I'm dealing with the Earth Observing System (EOS), a system that's rated at producing about 1 terabyte of data per day. When we talk about 1 terabyte of data per day, we need to put that in perspective. That's the equivalent of about a shelf of floppy disks seven and a half miles long. That's a 6250 BPI tape that circles the world being produced every day. The United States Geological Survey is going to have to start putting the land portion of that output in EROS Data Center. They had better start building extra rooms and/or we better improve our storage and retrieval media. We've done a few calculations that essentially show you can't write optical disks fast enough to keep up with a data stream of this magnitude at this time. We do have problems. These problems, however, are creating a variety of research opportunities. Opportunities that we as researchers need to vigorously pursue.

I'd summarize this session in terms of trends. We're moving from processing of data on local areas to global processing. We're moving from fixed applications available in the area of geographic information processing (essentially the GIS as a "tool-kit" approach).

What are we using these systems for? We began using GISs for mapping and for improving our understanding of maps and then we moved into monitoring changes that are occurring in our environment. Now we're moving into the more difficult problems of modeling and using GIS systems as aids in our modeling. Currently we are only linking simple models to GIS operations. However, we are rapidly increasing our sophistication in this area and I predict that we will soon be doing quite complex modeling within a GIS context.

With respect to hardware, initially we had machines in large boxes, but their processing power was small. Now we have small boxes, and the processing power is large. Here we have a lot going for us. We have more powerful systems available to more people to do more processing. With respect to these systems, we were using systems that consisted of homogeneous machines, and

now we have heterogeneous systems. We were into using centralized processing and/or processing facilities and now we're using distributive processing. Distributive processing implies networking and all the things that go with networking. Basically when we were using homogeneous systems, we were doing it ourselves. In other words, "Hey, I don't care what other people are doing. I'm going to develop my own standards and my own ways of using this darn thing." Whereas now that we're using heterogeneous systems, networks, and distributive processing linking research and applications centers and individuals around the country, we have more involvement in standards; not only in standard data units, but also standard formats. We've not only talked about ISO standards and FITS formats and so on, but how we get these things implemented. I could go on but suffice it to say that these are some of the key issues in this area that still need to be addressed.

In another key area, we are still to a very great extent using in our GISs maps of essentially unknown accuracy. How many maps do you know of that actually have documented accuracy? Let's not talk here about U.S. national map accuracy standards for topographic mapping. Let's talk about thematic maps. How many of these maps do you know of actually have map accuracy data associated with them? We've finally become very critically involved in this question of product accuracy. This is important. It is a major point.

Remember, in setting up a GIS we spend about 60 percent of our time just finding the right data products to use. And now we're going from the use of geographic information systems into what are called IGIS systems,--integrated geographic information systems. In these IGISs we're using data in a variety of forms, from a number of sources which have been processed on a variety of systems including: CAD/CAM; GIS technology; digital remotely sensed data and image processing; and, so on. How are we going to copy with the data products issues associated with these systems? What I have been discussing are the trends--trends generally towards increased complexity. Yet, I wonder how many of you have heard me use words like "parallel processing, or massively parallel processors", or "hypercubes". What's happening with these systems? I haven't even touched on the use of techniques from the field of Artificial Intelligence. I did not hear "knowledge"--I heard the words "AI" used--what about "knowledge-based systems"? What about tracing of data? Also, what about following the historical records and checking accuracy? Are we ever going to standardize on data structures? Do we even need to? These are some of the questions I would like to have more time to address.

I thank the speakers. They did an excellent job of presenting hardware, software, and applications trends occurring in the GIS area today. What I've done here briefly is summarize some of what was said. Thank you very much for allowing me to participate.

PLENARY SESSION 4. SPATIAL ANALYSIS AND ARTIFICIAL INTELLIGENCE

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PLENARY 4

SPATIAL ANALYSIS AND ARTIFICIAL INTELLIGENCE

CHAIR: Duane Marble, Ohio State University

PANEL: John R. Borchert, University of Minnesota
Nicholas R. Chrisman, University of Washington
Michael Dobson, Rand McNally and Company
Donna J. Peuquet, Pennsylvania State University
Keith Ord, Pennsylvania State University

GIS and Geography's Mission. John Borchert:

Twenty years ago I spoke to the opening session of the Fifth Annual Symposium on Remote Sensing of the Environment at the University of Michigan. I referred to a volume titled "The Scientific Endeavor," published in 1963 to commemorate the 100th anniversary of the National Academy of Sciences. The book was a collection of invited papers by some of the most distinguished physical and biological scientists at the time. It included such subtitles as "The History of the Universe," "The Nature of Matter," and "The Determinants of the Evolution of Life."

I wondered, for the science of geography, what is the possible equivalent of broad, deep, probing topics such as those. I concluded that there is an equivalent. For generations geography has studied the pattern of human settlement and circulation over the lands and waters of the world. One can look upon human circulation and settlement as a form of technology for utilizing the earth. And one basic question is, "What are the persistent characteristics of that technology down through the ages?" Another might be, "What are the characteristics of the evolution of that technology?"

In attempting to answer those questions, the science of geography is yet another way of probing the purpose, goals, and and the destiny of humankind. The tools required to conduct that probe must include a truly synoptic view of the world. Those tools would certainly be more effective in the age of remote sensors and computers, together with the accompanying advances at that time in our understanding of sampling, probability models, and generalized concepts of shape, texture, structure, and flow.

The same paper went on to discuss the relationships of geographic inquiry to general systems theory and to note work of Garrison, Marble, and others on geographic data requirements in the new age as we saw it then. I quoted extensively from their papers and certain other papers for four reasons. First, they summarized the categories of observations that geography uses. Second, they recognized both the inevitability and the value of a wide array of joint efforts not only among scientific fields but

also between the sciences and a wide array of other community enterprises. Third, they emphasized the obvious new strength remote sensing and computing gave to synoptic data networks. And, fourth, they reminded us that ground-based observation networks and archives offer competitive, and often superior, means of collecting some of the data.

It happened that a particularly appropriate letter had just found its way to my office through our wondrous campus mail directory system. An elderly gentleman in southeastern Minnesota had addressed the University of Minnesota, "Dear Sir: Would you please send me all available information on the glaciers in Minnesota from the first instance until they finally came under control?" It occurred to me that the glaciers could well get out of control again and overrun everything from the Mesabi Range to the Mayo Clinic or from Lake Placid to Levittown. In that case, we will need all of the remote sensing and computer-aided storage and analysis and international, multi-disciplinary cooperation we can possibly get.

So much for that speech twenty years ago. We all went off and cultivated our fields and grazed our pastures. In Minnesota we pursued the development of the state land management information system and studied the regional urban system and its evolution and its place in the nation.

Ten years later--a decade ago--I had to prepare a paper for possible use in what turned out to be an ill-fated "Health of the Environment" section of the National Academy of Science's "Five-Year Outlook." There I suggested a national system of land accounts to complement the national system of fiscal accounts. Let me repeat part of that paper.

"In the U.S. national fiscal accounts, land and structures comprise about half of the tangible assets, or nearly one-fourth of America's total assets. The growth and changing composition of those real property assets is an integral expression of the changing national map of land use and land value. The distribution of real property assets among different classes of owners on a statistical table in the nation's fiscal accounts is a kind of gross summary of the map of land ownership. And, of course, the changing map of land use reflects the mass of transactions that are monitored by the national fiscal accounts.

"Many people hear frequently about the gross national product, the share of it that is saved, and the share that is invested in land, new houses, offices, stores, factories, and nonbuilding structures. Many follow with great interest the changes in land value and the new development in their neighborhoods--local or global. But few have any idea of what share the latter is of the former--how the scene they observe fits into the panorama of the changing national economy as it is monitored and reported to them.

"Since Earth Day, Americans have been groping for a way to relate the impact of local projects on the land they know personally to the aggregate national economic and environmental condition. A national system of land accounts is not sufficient to resolve that search fully, but it is certainly necessary. The questions are: What is being done to develop such a system? What can be done?"

The paper went on to comment on the locations, quantity, and quality of information already scattered in federal and state agencies and local governments, and the wide range of sources--both remotely sensed and ground-based. It then alluded to limited efforts already initiated to organize and synthesize those scattered data sources in order to monitor changes in the land resource and its use.

"It seems certain that these efforts to develop systems of land resource accounting will continue to multiply because of the increasing scale and diversity of land needs and continuing conflicts over land allocation. There are some basic reasons why the land accounting system is likely to remain and grow as a public, not private, enterprise. Public agencies are already the main collectors of data. But more important is the fact that all levels of government need a land accounting system to conduct their own business as major land owners and resource managers. Equally important is the general public's need for such management information if it is to participate in the land management and policy-making responsibilities it now holds.

"Thus, it is also clear that the land accounting system will have to be built at all levels of government. Resource management and policy are functions of every level of government. Both legally and practically some issues are local, some regional or state-wide, some multi-state or national.

"The results of all these conditions are (1) a national land accounting system is likely to be built up from local through state systems, or, at least, all must be compatible; and (2) the system will not be exclusively a tool for a professional elite, since it is likely to be used as an important part of the general educational effort that must underlie land management decisions and policies in a democracy.

"... Major technical problems will have to be surmounted... The flow of events is forcing them upon us. The major issues center on terminology and classification, measurements, geographical structure of data and reference schemes, cooperation and coordination among scientific fields and institutions, and--most important of all--the specific purposes to be served."

Then the paper alluded to the interaction between such an accounting system and the research enterprise. And I concluded with these observations.

"A national system of land accounts would have great long-run value for both the development and the application of sciences related to resource management. Such a system would help to monitor additions to or withdrawals from the nation's land inventory--to know how much land of what resource characteristics has had its use altered in what way, with what resulting change in the nation's tangible assets, under what class of ownership. The system would also help to evaluate and improve the quality of analyses and projections; to know the applicability of gross national figures to different localities; and the results--on the land--of different public programs and market trends. Perhaps most important in the long run, the system would provide an improved database for the sciences concerned with understanding basic processes in the evolving relation between human settlements and their natural environments.

"While the process of land use change has ... important spatial elements and interrelations, it is more fundamentally a reflection of complex social interactions and decisions. If information about the land is both improved and more accessible, that in itself will affect subsequent land use decisions. Again, there is a need for much more understanding of the role of information about the land in resolving conflicts between buyers, sellers, developers (both private and public), affected third parties--local or global--and public officials. Research on that subject has been restricted in both substance and impact because of the absence of a nation-wide data system. A deeper understanding is important to the success of a democracy.

Last year--a decade later--the International Council of Scientific Unions--of which the International Geographical Union is one of the charter members--formally launched an International Geosphere Biosphere Program. The purpose of that ambitious, comprehensive program is to synthesize the record of global environmental change, extend it, and improve the quality and coverage. The projected program centers strongly in the physical and biological sciences. But the rhetoric of the proposed program is holistic, and it ramifies in many places into the realm of human settlement and land use. Proposed research outlines on the biosphere, atmosphere, and hydrologic cycle imply vast knowledge of the quantitative geography of commercial crops, cattle, farmland clearing and development, industrial production, transportation facilities, and urban development. The proposals also imply the need for vast understanding of the problems of sampling, scale, process, modeling, forecasting, monitoring, and evaluation that you have been clawing at in this conference. In short, I think the IGBP implies the need for a global system of land accounts.

Sweeping and holistic as it sounds, the IGBP is still only one of several such efforts in the making, which will also imply the need for many aspects of a global land accounts system. Others are the International Decade of Natural Hazards Reduction

and an international research program on Human Response to Global Change. The latter program is in many ways a complementary response to the natural science questions about human intervention in the long-term natural processes that affect global habitability. Indeed, a significant side issue might well be how to keep track of the burgeoning number of global social and economic organizations promoting the scientific study of global change.

Now, if I have the good fortune to have to say something about this ongoing, braided stream of geographical scientific missions after yet another decade has elapsed, what am I likely to say? It would be good to be able to review a decade of even more remarkable progress toward resolving the problems of scale, sampling, standardization, classification, data structure, modeling, forecasting, monitoring, evaluation, and inter-institutional coordination, to outline the progress toward a U.S. national system of land accounts and the way it articulates with a growing world system of land accounts.

Ideally, there will be illuminating, exciting, new, substantive books--or the electronic equivalents--on the changing geography of dozens of major regions of the world that synthesize the swelling flow of information and contribute a much-improved body of understanding and new, increasingly penetrating, substantive questions about specifically what is going on. Ideally, there will be books that compare and synthesize the experience of use of this knowledge by the officials and legislative bodies and the citizenry of large organizations or regions around the world. And there will be a growing body of studies that measure land use changes in units that are comparable and convertible into those used by the natural sciences to measure biogeochemical cycles and the hydrologic cycle.

I'll review those achievements, and then I'll be ready to join Colby, Finch, Sauer, and the others to whom Nick Chrisman refers, if they'll accept me as a neighbor on that Great Global Land Use Observation Platform in the sky.

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Challenges for Research in Geographic Information Systems

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ABSTRACT

Research in geographic information systems must be broadly based, drawing on deep roots within diverse disciplines. The common characterization of research as "basic" or "applied" impedes progress; a more useful distinction contrasts the development of tools and the examination of outcomes. In the realm of tool development, representation of spatial information must extend beyond measurements of location and attributes to include data quality. Despite the current focus on GIS tools, greater challenges will come from studying outcomes – the fundamental questions "Why?" and "So what?".

BACKGROUND

Over the past ten years, research in geographic information systems (GIS) has grown from a fringe activity to a current solicitation from the National Science Foundation for a National Center. This change has been eclipsed by the much larger development of operational GIS installations. The research community has dealt primarily with a narrow set of technical issues and has not responded to some of the most crucial challenges. This paper will attempt to cover the full range of challenges for GIS research. A fully balanced review of current research and future prospects, accompanied by the requisite references, would exceed the scope of this paper. Hence, this presentation will include very limited references, and must be treated primarily as an opinion piece.

As background, this first section will review the intellectual origins of GIS research and some of the pressures from the world of practical application. These topics lead to a classification of research used below.

Disciplinary Context of GIS Research

The cult of novelty and "high" technology may blind us to the roots of development for the various disciplines involved in geographic information systems. As a geographer, I am particularly aware of the intellectual roots in my own discipline. Sauer's (1919) early work in Michigan's Upper Peninsula and the land use studies of Whittlesey,

Finch and other contemporaries foreshadowed the current emphasis on layers of thematic information. Charles Colby (1936) delivered a visionary presidential address on the research challenges to geography with emphasis on the development of more quantitative methods for map-based problems. Such studies fell out of the research vanguard in geography, but remain important in landscape architecture and environmental planning. The roots of map overlay, a central tool in current GIS, have been traced back one hundred years in the field of landscape architecture (Steinitz and others, 1976). As environmental issues became a major focus of public attention in the 1960s, practicing landscape architects like Phillip Lewis played a more influential role than geographers, and Ian McHarg's *Design with Nature* (1969) captured a broad readership. In many respects, a modern information system is nothing new at all, in so far as its goals were understood long before the computer age.

The quantitative period in geography challenged the discipline's established direction. New analytical methods were explored, often as imports from other disciplines. Some writers, notably Bunge (1966) and Warntz (1968), hinted at the methods we now call GIS. In a rather forgotten discussion collection titled "The Philosophy of Maps", Warntz ends a presentation on set theory and spatial analysis with this call for future research:

> "Some one should write a book on regionalization. It might well have the following title:
> *The Algebra of Sets, Geographical Regions and the Use of Some Obvious but Hitherto Ignored Properties of Venn Diagrams -- Or the Logic and Method of Geographical Regionalization as an Extension of Boolean Algebra Examining the Relationship of General Classification Theory, Symbolic Logic, the Algebra of Sets, Computers, Electronic Circuitry, and Logic Diagrams with Special Consideration of Automated Logic Machines and the Representation of Systems of Geographical Regions Based on a Rational Interpretation of Non-Spatial Differences and Geographical Distances, that is to say the Theory and Application of the Geographical Analysis of Variance.*
>
> We sometimes make our greatest gains in geography when it is our basic concepts that are simple and natural and our techniques that are sophisticated." (Warntz, 1968, p. 30)

In large part, the computers and software of the era could not meet these challenges. By now, some of Warntz's research agenda has been addressed, though not entirely by geographers. The issue of "regionalization" has not been as central an analytical method, though it relates to the classification problems of remote sensing. The current development of GIS has overcome many of the prior problems, but not all difficulty has been resolved.

The study of mapping and spatial information is inherently multidisciplinary, spanning from the most precisely defined engineering disciplines (geodesy and surveying) to the presentation arts of cartography, also including social and behavioral approaches. Without belaboring the references, the purpose of a GIS fits into the long-standing directions of these various disciplines. Until recently, the time to revise techniques was not ripe. GIS development may revolutitionize methodology, but the GIS does not revolutionize the more fundamental goals because it delivers tools for tasks long recognized.

Applications Context of GIS Research

The use of GIS in the public arena has now gone beyond pilot projects as many agencies and companies begin to apply the technology in their core activities. The increase in GIS application will, and should, exert pressure on the research community. The world of applications offers particular challenges to academic theory. For instance, while research workers discuss large databases, GIS practitioners are amassing truly stupendous databases. These two groups should not remain isolated by barriers of outlook. There seems to be nothing as powerful as a demanding application to find holes in an elegant theoretical scheme.

Most current systems are still in the phase of data entry, usually through digitizing existing paper maps. The use of a map archive as a source may be economically justified, but it limits the vision of the scope of an information system. As an implemented system matures, primary sources closer to the events must replace the traditional map source. In the few cases where this change has occurred. the attitudes toward information have shifted. The traditional map is no longer an adequate model for the content of the information system. A GIS is much more than an automated atlas, for a variety of reasons. In the place of associative, intuitive map reading processes, GIS analysis requires explicit procedures and a clearer application of logic.

Some remarkable advances have been made in our understanding of geographic information, but much more remains to be tackled. The GIS software now being installed worldwide is based on research performed ten or more years ago, mostly in university settings. While it was relatively easy then for the typical academic team to conduct innovative research, the scale of current systems makes it more complicated for today's academics to contribute in the same ways. The structure of the research community, whether it consists of individual scholar/monks, large corporate teams or a National Center is an important topic, but it must remain subservient to the more basic question - what are the current challenges for research in GIS?

Classification of Research

The terms *basic* and *applied* arise whenever research is classified, but their meanings are ambiguous. Due to different perspectives, what is applied to some seems basic to others. It is an unfortunate fact of multidisciplinary cooperation that any researcher is most likely to consider their work as basic and to classify the work of others as simple applications. Clapp and others (1985) offer a partial solution to this dilemma. They present a scheme of evaluation for a GIS based on a scale of comprehensiveness covering operational efficiency, operational effectiveness, program effectiveness and contributions to well-being. This scheme demonstrates how issues which are basic in developing efficiency become applied at more cosmic levels. The tension between efficiency and effectiveness is particularly important, but often not as linear as their model of program evaluation expects.

This paper divides the research agenda into two general themes: tool development and outcomes. These two themes serve as a logical fulcrum for GIS research. It is hard to say which will lead to the "deepest" theory and the greatest advances, in fact may be divisive to ask the question. There cannot be a single theory acceptable to such a broad range of disciplines, due to the diverse definitions of theory. Also, there is no dearth of theory, only a lack of critical assessment and reformulation of the existing corpus.

TOOL DEVELOPMENT

The category "tool development" covers the bulk of current GIS research [with the exceptions noted below]. "Tool development" may seem a strange category for fundamental research, but the category is apt, because good software tools require careful attention to conceptual understanding. This essay will consider the distinct layers of abstraction from conceptualization through logical structure to physical implementation as an integral process of tool development. Tool development fits into Clapp's model primarily in the search for operational efficiency, as in the use of computing resources. Issues of effectiveness are described in the outcomes section. This section will present some of the research challenges for tool development in two main groups; first, the issues of representation, then the tools of manipulation, display and analysis.

Representation of Spatial Data

Representation plays a key role in a GIS, particularly because choices of fundamental models constrain implementation. Geographic

information has special problems that require theoretical attention. A reductionist approach adopts a limited theory of relationships, thus overlooking important interactions and weakening the system. Other mistaken developments place too great an emphasis on techniques conceived for different circumstances or presume that small prototype research will scale up to handle full–scale problems.

Geometric Sciences. Development of GIS requires a theory of spatial relations that incorporates fundamentals of topology, projective geometry, and terrestrial geodesy – fields which, collectively, have ancient roots, and very recent developments.

If there is a fundamental spatial theory, it must begin with the topological approach to map information. This relatively simple "theory" has proven itself in practical application as a useful armature for building a system of representation. Even the most recalcitrant system vendors have adopted the faith. Perhaps the frequent call for a basic spatial theory is motivated by the hope that some compelling theory exists that could might prove as useful as topology. If so, it is unlikely to be as obvious.

Although many consider geodetic control to be a technical component of mapping, it now serves a more important role. The geometric fabric of a data structure is the basis of analytical tools like polygon overlay. A number of authors have demonstrated that most analytical tools can be reduced to transformations within a layer followed by overlay of two layers. This emphasizes the reliance on geodetic relationships (absolute, not relative positional accuracy). The relation of data to the control system is a major area to develop and understand. At the very time that geodetic control is in greater demand, it is also getting cheaper through new technology such as Global Positioning System (GPS). While the cost reduction is welcome, it makes it difficult to plan for GIS development. Even though recently revised, the new geodetic standards still downgrade networks that are both highly accurate and closely spaced. A new approach to positional accuracy may solve the problem, but some dilemmas in the geodetic mathematics are inescapable.

These baldly geometric aspects of spatial data are necessary but far from sufficient. Any information, to become useful, must include a reference to "how you know that you know it" – epistemology. XYZ coordinates are not the full "phase space" for GIS data; information on quality and time provide the analogue of accelerations in physics. In addition, information is a social commodity, collected by specific institutions acting within a cultural context. Thus the issues of representation expand from coordinate geometry to cover the full life cycle of information.

The Quality Dimension. The original impetus for the topological model was the need to check a database's logical consistency automatically, for example, the DIME structure can be used to detect missing or improperly coded street segments. Concern for logical consistency suggests other dimensions of data beyond geometric facts. Recent work on the US national standard for data quality has codified five issues to be included along with a digital transmission to permit a recipient to judge the fitness for a particular use. These five topics are lineage, positional accuracy, attribute accuracy, logical consistency and completeness. Most of the concern in the mapping sciences has focused on the accuracy of positions as the talisman of quality. Yet the identity, consistency and completeness of the objects mapped are at least as crucial to data quality. Taken together, the five components provide the basis for evaluating data. In Newtonian mechanics, an acceleration provides a means to represent the behavior of a body beyond the information inherent in a coordinate position. In a similar manner, data quality provides hidden dimensions of the "phase space" of geographic information. [Goodchild and Dubuc (1987) also use the term phase space for the taxonomic space that underlies certain categorical maps.] Other authors (e.g., Burrough, 1986) demonstrate the linkage between error theory to analytical purposes; this subject cannot be overemphasized.

In addition, a spatial data structure must be extended to handle temporal issues, such as the flows of changes in the phenomenon, the bureaucratic flows in producing the database, and perhaps even the future worlds we might try to imagine with the database. The lineage component of the quality report mentioned above provides the accumulated historical audit trail of sources and procedures used to build a database. Very few digital systems are capable of providing a comprehensive lineage report. Too frequently, digital processing does not deserve its aura of precision and modernity.

Institutional Factors. While geometry and related issues are important, the meaning of spatial data comes from its societal context. The current vogue of user needs assessment misses some crucial components, if it assumes that the predigital system does what it was designed to do. Current systems are constrained by many factors, including the archaic technology of mapping. A more fundamental approach should recognize the underlying societal goals – already formalized as legal mandates for custodian institutions. Some research presumes that fundamental spatial relations must arise from abstract mathematics, far from legal and cultural constraints. An effective data structure should not require a pure mathematical vision, but must proceed from where society is to where it can reasonably hope to get. The guiding rules should avoid degrading the information content, and attempt to serve as broad a range of needs (multipurpose) as possible.

Beyond Representation

Although the issues of representation take first priority in tool development, there are other important issues in developing tools that manipulate, transform, display and analyze geographic information. This section will discuss a few of these issues.

Algorithms. Through ten years of research, greater emphasis has been placed on database architecture than on programming. Much of this change in emphasis is correct and healthy. A system of representation can incorporate many relationships which older programs had to construct laboriously. Still, algorithmic design must be included as a research challenge, because geographic problems are inherently data intense. Big is different in algorithmic complexity analysis.

The balance of cost between computation and memory has shifted over the past decade, favoring a database approach. In the future the shift may move in a different direction. The issues of representation may change dramatically with the development of new generations of computer architecture. The current sequential model of computers is remarkably robust after forty years of development, but the limits of this architecture are close. Although the advent of parallel processing has been trumpeted for years with little delivered on the promises, the options have become broader. Some years ago, parallel computing was expected to provide lockstep operations for raster data, but now frame buffers and image processors are not the only form of parallelism under investigation. One alternative is the "dataflow" computer, a particularly attractive option for the current GIS software systems that apply dataflow concepts on sequential computers (Chrisman, 1976).

Advanced computer science. In many circles, emphasis on algorithms is out of fashion. Information systems can be developed around the current research in computer science covered by a variety of terms, including artificial intelligence, rule-based systems, expert systems, object-oriented systems. Without discussing the differences of these research fields, the GIS world has taken notice, and should take notice of these potentially exciting developments. However, each new development in computer science may be investigated by a true believer who may not consider all of the limitations of the original research. There tend to be papers like those from the period of quantitative experimentation, where the author simply introduces a new approach from elsewhere often without examining the limitations and consequences. Advanced methods are no magic bullet and are at least as difficult to construct as more classical programming. Certainly, these topics are part of the research frontier, but they should not be treated as the secret passage to the promised land.

Analytical procedures. A most critical need is to sharpen the tools of analysis. Use of spatial information to study spatial patterns and associations has deep roots, but most practitioners would admit to limitations of the current analytical tools. In some simple matters, tools for spatially distributed data show a weakness compared to the standards of other sciences. Beyond the painstaking presentations of a surveyor, presentations of spatial data rarely include an error bar for the measurements portrayed. The lack of a proper theory of error is why Warntz's Spatial Analysis of Variance has not been created yet. The research agenda for spatial error forms the subject of my other paper presented at this symposium.

Many analytical procedures developed in other disciplines warrant attention. The spatial statistics of agricultural experiments, geology and even physics are more advanced than geographic ones. However, each of these disciplines developed their method from their particular theoretical base and from their error theory. Because tools instantiate theories, borrowing from other disciplines is counterproductive. Instead we must understand the meaning and importance of geographic information, and build our own suite of analytical tools.

Graphics and the human interface. One other issue of tool development involves tools for visualization and presentation. Cartographers knew how to lie with maps for centuries before statistics were invented. The convincing character of graphic presentation is a weighty responsibility. The modern automated system has not created a creative surge in mapping. Quite the contrary, many "computer atlases" reproduce hideous maps that confuse and misinform. As a general duty to the consumer, the research community must attend to the quality of graphic products. As a research topic, the study of perception of graphics has occupied many academic cartographers for the past decades. These studies have still not built a revised technique. Beyond traditional graphics, the GIS offers a broader range of interaction between the information and the user. These should be explored, but with a studied sense of purpose, and not simply for flashy technology.

OUTCOMES

While the development of GIS tools must be conducted in the arcane confines of modern computers, the outcomes of using the GIS should be considered in a different context. The nature of an information system can have an impact on the questions it can address. Conversely, the special demands of an application can require new tools. In either case, research must consider the outcomes of a GIS along with the tools. A selection of outcome topics are discussed below.

While tool development tends to be driven by measures of efficiency, an information system must operate inside a social system. The goals of the social system are diverse. Perhaps, in the theoretical capitalist firm, a management information system may be motivated solely by efficiency. But this situation is not common in business operations that consider their public image and their impact on the community. Societal values usually counterbalance the lure of efficiency with other goals discussed below. Clapp and others (1985) include distinct levels in their model from operational and program effectiveness to well-being. To some extent, these levels simply carry the distinction between tools and outcomes to additional layers of abstraction. However, the process is not quite so linear, and outcomes place demands on tools.

Critical Applications

GIS has grown up in a crisis environment. Many early developments were tied to the current issues of the day, such as nuclear power plant location, environmental impact statements, or urban renewal. The lure of the "hot topic" attracted some attention, but the systems tended to die once the initial crisis was over. Now, greater emphasis must be placed on routine application and tools to confront the mundane and uninteresting topics that dominate local government. Some of the reasons for the focus on local government is due to the mandates for detailed data which reside at this level, and also due to some issues discussed as other outcomes. While not a flashy research agenda, a concern for routine custodians does not preclude parallel attention to more visible issues.

Some of the largest topics of research interest, such as global habitability, planetary oxygen demand, and the greenhouse effect, have the potential to affect the surface of the earth as the home of man. Information is central to these tough problems, but not enough is available. Research focussed on tool development may help confront critical applications, but tools are not simply geometric axioms pursued for their pure beauty. A special set of issues are raised by each application. Global data requires particular attention to issues of scale and accuracy, because data of dubious origins will be the only sources available in regions suffering from various problems such as deforestation and desertification. Specific tool development is required to extrapolate from flawed data to areas of continental extent.

Balancing Competing Concerns

Many GIS applications can be grouped under the general issue of balance between competing concerns. Some public decisions balance benefit/cost or risk/cost; others involve environment/development, or

regulation/incentives (carrot/stick). There is a growing literature on unwanted facilities, sometimes called LULU's (Locally Unwanted Land Uses) or NIMBY's (Not In My BackYard). The bulk of these facilities involve mundane landfills or homeless shelters, but the principles apply equally to nuclear waste repositories and other issues of national concern. Although each of these topics forms the subject of different research, the issue of competing concerns covers them collectively. Existing location theory must be reformulated to include information handling, the social perceptions of facilities and the impact of public participation on decisions. Just as global problems require particular tools, the search for balance will require an information system to perform functions that are not required for efficiency.

The role of information systems in the balancing process is an important social science research question. An information system might be termed one kind of success when all participants accept the data and tools as neutral. Neutrality does not require all elements in society to reach the same conclusions, but it makes the debate focus on substantive issues, not disagreements on evidence. There are some cases where a GIS has served a neutral role and improved the balancing process for all participants. Such cases require careful study to determine how neutrality might be achieved. If the hypothesis of neutrality cannot be upheld, then the development of tools must be subject to much greater scrutiny. Which group in society is being served, at the expense of which other one? Do certain tools favor one group's viewpoint? The future of GIS depends on serving important societal needs, such as the balancing of competing concerns, much more than it depends on technological advances.

Equity and Equality

The process of balancing competing concerns is typically controlled by overall societal outcomes, not the cost of processing the information. One special issue of balance involves the heavily loaded terms equality and equity. *Equality* is a strict social goal applied to certain rights and responsibilities, but strictly equal allocation is rarely the solution sought. Much of the information collected and maintained by public agencies is involved in ensuring *equity*, a fair allocation of resources. These concerns deserve special consideration beyond a general theory for balancing competing concerns.

A functioning GIS must be tested to see if it improves the equity in the final decisions as we may all hope. Currently there is little hard evidence to support these hopes. If a particular information system is not enhancing social goals such as equity, what feature of the information system is responsible? Is it possible to predict the outcome? To study these issues, some retrospective studies and baselines for

future studies must be started. One alternative to the technocratic hypothesis of neutrality is an information system which quantifies and clarifies inequity, causing a new consensus to be constructed.

Disaggregate Evidence

Outcomes of new tools in the sciences need not focus on over-arching social goals. In some respects, we should be more parochial and anticipate the impact of GIS tools on the disciplines that use spatial evidence. A new tool may not seem likely to change the structure of a science, but there are many cases where a tool lead to reconstructed theory. Some of the largest steps in scientific development have been driven by changes in tools that changed the level of detail available for analysis. As an example, the resolution of finer and finer structure has driven physics from "elemental" atoms through particles and now to quarks. Although advances in physics may seem far removed from geographic research, availability of information limits our detailed knowledge of many social, economic and environmental processes.

Access to more detailed data, a consequence of expanded operational GIS, will require revision and reexamination of disciplines whose analysis has been constrained by lack of information. Geographers have been forced to deal with aggregate statistics on such issues as land use change, due to the lack of information. As the GIS tools become operational in local government, there will be an unanticipated effect in delivering a new richness of detail to the research community. The availability of more detailed information may foster a revival of many currents in geographic research whose theories were unproven or unworkable. The depth of detail may not be exploited until the disciplines recognize the possibilities.

CONCLUSIONS

In conclusion, one prime question may be the proper disciplinary niche for research in geographic information systems. Can the developments in GIS create a brand-new discipline? – probably not. These topics are the proper issues of many existing disciplines and further scientific fragmentation will not be helpful. In both tool development and outcomes, some GIS research has taken the easy importer route that typified the period of quantitative development in geography and many other social sciences. GIS research too often consists of importing a bright idea from computer science or economics, and implementing it in the particular context of geographic information. Importing is one viable source of new ideas, but if it is the only source of ideas, there is slim hope for interesting research.

Despite the rhetorical concentration on outcomes, both tool development and outcomes must be studied. Efficiency of tools is an important goal, leading to practical results and the satisfaction of mathematical purity. Research on outcomes is much less developed, with many implications. If research in geographic information systems can maintain the parallel interest in tool development and in outcomes, then new theory will develop grounded in the intricacies of spatial data and the world they represent. This new theory is unlikely to arise from nothing, it will develop from the parts of our intellectual heritage that we manage to remember and that we can adapt to our changing circumstances. The research community requires the divergent opinions and skills of a wide range of disciplines and schools of thought to move forward.

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Michael Dobson:

I plan on covering several things this morning. I'm neither as prepared or as suave as the two previous speakers. Rather I'm irritated, and I'm irritated by a lot of things I've heard at this conference and a lot of things that I haven't heard at this conference, and I'm specifically irritated with the status of cartography and where we should be going, and I think artificial intelligence is a wonderful topic because whether geographers or cartographers develop expert systems might be somewhat irrelevant. Someone is going to.

The only issue is whether we'll have any knowledge to input into these systems or the chance to do it. And the answer right now is "no." There are people out there who would be certainly willing to jump into the ball game as quickly as possible. I think perhaps some of the recent activities in relation to a national GIS center certainly proved that when people see money, they'll be willing to come into the arena.

So what do we need to think about if we're going to research artificial intelligence? Please understand that being a large-scale producer of maps as Director of Cartographic Services at Rand McNally, I would also love to have an expert production system to create my product. I would love to have a massive database to crank products out for the consumers of America. Right now, I deal mostly with 140 cartographers, and that's sort of the sin that I have to pay for, isn't it? As an educator over the years, I've turned out hundreds of cartographers. And now they're working for me! They remember all the things that I told them about cartography; they're telling me what they have to do when they do that map and know they can't cut corners and know it's not going to cost less, and I'm going, "Good Golly. What did I do?"

We cartographers have been guilty of cloning ourselves. We have been guilty of cloning some rules and goals that may no longer be in balance with a cartographic production environment. If we were to stop and just sit back for a second and think about what systems might do for us if we were talking expert systems or some variant, we'd have to realize that the computer obviously has to have some method, some set of step-by-step instructions to allow it to perform a task in complete detail. We'd also have to realize that (1) the machine can't compensate for its lacks by brute computational strength, and (2) we'd have to realize the most "horrifying thing" is that the detailed steps of almost all intelligent human behavior are unknown. And all of you that make maps must sometimes question whether making maps is intelligent human behavior.

I say that for a variety of reasons. For example, we have people now trying to model generalization on machines, but you're going to have a hard time modeling generalization. You're going to have a hard time extracting from the cartographer how he or

she generalizes data. And while at this point in time we are dealing with line generalization which I consider (and I hope no one gets offended at this but you may) to be one of the more trivial problems in generalization. I consider some problems in data generalization and symbolization to be much more difficult than the relationship between lines and what's on the map. How do you generalize? What do cartographers do with this great body of mystique that we've built up? (And, yes, much of it has been mystique.) It's going to be very difficult to deal with our theories in a computerized environment. Maybe we need to do something different. Maybe we need to think a little bit differently about what we're doing.

But the effect of the constraints that I just mentioned suggests that what we're dealing with (if we're going to have a machine do things for us) is the concept that the machine is going to model behavior. Now that's going to require several things, too. It's going to require information about intelligence. It's going to require that we know something, an analysis at least, about what we might call competence (as influenced by context and content), and which basically says that for a specific class of tasks, how is the competence required for the task performance best characterized to reflect human behavior.

Now do you really want to think about modeling a cartographer's behavior? I was one, and I know that all of my students and all of my colleagues and even the people that I worked for regarded me to be <u>at least</u> a unique personality. Most cartographers are regarded as being human oddities. We have ways that we do things. We have been apprentices. We have followed some cartographic god around and picked up information. But what we haven't done very much is question that information. We don't know why we do all the things we do. We don't even know if many of the relationships that we use to symbolize data on maps are valid. They are conventional. We have done them for years. They make sense, but in a era where we have immense computational and graphic capabilities for on-screen displays, is it necessary to continue to produce dot maps? Could we not think of new ways to produce flow data? Do we still have to deal with that age-old problem that's akin to psoriasis--yes, the choropleth class interval problem--scaling. Do we have to continue to deal with that?

Years ago, Waldo Tobler brought up an article on class intervals that was a wonderful article that he and I got into many debates about. The very sad part is that in that article Waldo suggested three or four alternative methods to presenting choroplethic data that no one ever looked at. The argument about continuous or noncontinuous grade scales is really an irrelevant argument. What do you want to do with it? Do you want to look at the map and see pattern? Then do what Waldo says. But what cartographers haven't thought about--and I wasn't going to give up on this because I got a heck of a lot of articles out of the

topic--is that if we have intelligent systems and you want to interrogate the database, damn it, don't draw a map. Ask it what the value for that state is. Ask it what the value for the variable is. You don't need to know anything about color. If you want the pattern, ask for a pattern display. If you want the value, ask for the value--not a symbol.

The critical issue, the basic issue, is that if you wanted to find absolute values from displays, the last thing you would want to use for mensuration is your eyeball. It's not very good at determining color changes, grade scale changes, or measuring size. But you know what it's really good at? It's good at seeing motion. It's good at seeing what's different in this picture. You show someone a picture of Florida in which southern Florida is in a jock strap and they will notice that immediately. What's different? What's wrong? That's what the eye does. It doesn't measure. It's a very poor measurement device. And yet all of our cartographic symbolism is designed to let the eye measure spatial data and come up with an a real storehouse concept. Maybe we've made a big mistake. Maybe new technology offers us a different way to pursue this data, to present this data, and to integrate the data into a systemic operation.

We also need to have information about cognitive theory; that is, given a specific task and the available knowledge relative to performing the task, what mechanism determines how this knowledge is applied and how new task-related knowledge is acquired? Well, that's another real difficult one for cartographers to answer, and we have been somewhat reluctant to research this issue. Cartographers--and I'm perhaps speaking for too many people other than myself, but I have a long history in cartography--are very apt to answer everything as exception handling: "This is not the same problem as this. This is not the same data. This does not require the same base."

Well, the explosion of possibilities of map bases and data and symbolization schemes is indeed enormous. Given new technology, given what systems can do for us, given new procedures, maybe we can do lots of things that relate to map data and new modes of presentation. A lot of people can't use maps. They look at a map, and they don't understand it. And as we know, one spouse reading a map in a car while the other spouse is driving has been the major cause of divorce in the United States. Rand McNally hears about this all the time! You know, I feel like Jane Curtain on Saturday Night Live. I get these letters, and they just basically say, "You .... " And I say, "yes." "Well so what if you made 21,000 changes in the Rand McNally Road Atlas, you missed this one." We get that all the time. On the more serious side, we must concede the cartographers do not know even the basics when it comes to understanding the transmission of data from maps to map readers, and it is difficult to model an unknown.

The other part of dealing with machines says that we need to

know something about measurement. We need to know the relationship between competence and knowledge, and how does one determine what an individual knows relative to a specific content domain that is required to solve that problem? Well, ask some cartographers. I grew up with George Jenks. I wouldn't have the nerve to ask George Jenks that question. "How do you know, George?" It would have been expletives deleted for four or five minutes. He would have beat me and chased me around the lab and then said, "That's what you get, you young punk." And any of you who work with George know that that's true.

If we put all these things together, we must realize that we need several research activities. We need to have some expertise (if we're going to create one of these systems) about the content domain. We will also need to have a brand of logical reasoning which is a way of focusing on factors in the content domain that are relative to a specific problem. We will need to have a natural language that's a front end to a system that could be a mapping system of some sort, a GIS system and a spatial programming system. Well, I'm not terribly concerned with the language of programming because there are some smart people out there, (and they may be us, and they may not be us). However, what we bring to this application, quite obviously, is knowledge about the content domain and knowledge about the procedures required to operate on the content domain.

But, sometimes when I come to these conferences, it seems that what's needed is a basic tutorial, that everybody needs to go back and look at Arthur Robinson's textbook and read the sections about generalization, symbolization, and classification, and understand what generalization, symbolization, and classification are because I'm not sure many people do. And I think we need to review concepts and classifications. We're always dealing with nominal, ordinal, interval, and ratio data. Do we need to deal with that concept any more? I heard Waldo say today he wasn't very interested in dealing with line or point data. He didn't think that was particularly relevant. Well, it's very nice for us to get up here and tell you this, but what does all that mean? What are the alternatives? What should we be thinking about? Where should we be going? And don't you wonder sometimes when you're listening to speeches on accuracy and generalization, why nobody ever goes into the things that those old-time cartographers called the controls of generalization, you know, the objective of the map? I listen to people talk about accuracy, and I say, "Well, you know, I make paper maps, and I make a lot of road maps, and we make them for people who drive cars." And what a person who drives a car wants to know is whether the next street is the right street--is the next town the right town?--so that they can turn. Whether that line is 10 feet off, 20 feet off, 30 feet off, or 100 feet off doesn't make a difference to a person in the car. But I do question why my cartographers go out and research golf courses and find out where the clubhouse is and put the flag on the map where the clubhouse is. Do you need to know that? I also

question why we laboriously put all the possible variations and convolutions of the off and on ramps on maps. Why not put a symbol? If it looks like four mice in a beer can with the tails coming out, you can get on four ways. If it's not there, you can't get on. Do you (when you're driving a car) follow the line on the map and get ready to curve? Well, to be honest with you, most of the time when I drive, I black out and somehow I arrive there. I don't know how I get there.

Don Cooke was mentioning that some people need to have printed lists, and for some people that's a great way of taking cartographic data and making it useful. And for those very same people, having a road map wouldn't work. But have we thought about why? Do we know anything about why? Do we prepare systems that can go either way? Usually, no.

All too often we forget cartographic objectives; i.e., why are you making the map? When I look at accuracy, it's accuracy for what purpose? I heard Nick Chrisman talk about doing all sorts of things yesterday, comparing maps, comparing accuracies. Well, on a lot of maps, accuracy just doesn't matter. Accuracy of what? Accuracy of line work doesn't matter on most thematic maps. I've done experiments where I have shown humans (yes, people who can walk and talk, those famous subjects of all American psychological experiments, the college student) maps of the United States with distributions on them. I've shown them these maps for 51 thousandths of a second. That is technically quicker than you can image on the eye. And then I take it away, and being a typical college prof that I used to be, I'd say, "Well, what did you see?" They all saw the United States. They saw the outline of the border of the United States. They saw a distribution of some variable in the United States; they knew spatially where it was; they couldn't read the title because they didn't have time to read the title, but they captured an image.

Now when some of them looked at the border of the United States, it was awfully simplified. It was sort of like six triangles and a banana, not with all the little squiggles. They didn't know it. There is a lot of data in visual search and visual science that indicates that you acquire an image in the first half of a second when you look at it, and the rest of the time you spend looking at it you're just reaffirming what you thought you saw before but you're so scared that you didn't really see it that you keep looking again. That's the way we work. We keep looking back. When we read a book, we go, "Did it really say that?" Well, we read maps the same way.

We need to start tying some of these concepts together. But if you begin to look at data capture, data conversion, conversion to maps symbology, information development, assignment of symbols to map space, and the selection of the nonspatial components of symbolism for a mapping system, there is an awfully large research agenda for all of you. Each of you could take a part, and we'll never be finished.

We need to think about a couple interesting things that I will leave you with that are difficult problems for me that I haven't heard a lot about in this conference. I'm very interested in all the techniques and all the activities that everyone here has talked about. However, nobody's talked about the cost of integrated research bases. I can tell you that Rand McNally just completed a very large mapping project involving a three-county street map of the Detroit area done entirely digitally. We put together an accounting system. We have tracked every possible cost that is related to this map. And I'd like to share it with you, but I'm not going to. However, I know what digital mapping in a production environment costs, and do you know what the horrifying thing is? It costs more to gather the data than to write all of the code, do all of the digitizing, do all of the symbolizing, and photo plot all of the output. There were no federal sources available that had the type of information that we needed, that had the currency that we needed, so we spent more to gather the data than to display it. So I do worry about the cost of hardware, but an incredibly difficult part of using that hardware is to find some way to effectively use information and to acquire current information that is comprehensive for the products that you want. And if you think that you can solve the problem by simply importing data that is out there, ask yourself who's going to update it for you in '92, '93, '94, '95, '96, '97, '98, '99--nobody. Difficult question, isn't it?

Just two other points. One question is what are the economics of large-scale production. We are all apt to sit here and deal with problems of data massaging and where the profession should be going. What about the money? What does it cost? Can people afford it? Is it useful? Is there a payback? Is there a return on the investment? Applications people very rarely talk about economics and practicality. And it is very tenuous as to whether there's a return on the investment. There needs to be more promise in geographic information systems and more promise in digital cartography before it really happens. There will be a proliferation of activity, absolutely no doubt. Whether it will be useful is yet another and a very serious question.

I think I have caused enough problems for today and anyway, my dilithium crystals are weakening. Thanks for your attention.

RESEARCH ISSUES IN ARTIFICIAL INTELLIGENCE AND GEOGRAPHIC INFORMATION SYSTEMS

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INTRODUCTION

The storage, display, manipulation and analysis of geographic data via geographic information systems (GISs) is now common practice in private and governmental organizations. There is within this a rapidly growing need to use GISs to manage databases that are extremely large (national or global in scope) and are to be shared by a wide variety of applications. Nevertheless, attempts to build such systems have revealed many problems. Some of these have implications that go beyond GIS technology itself and involve issues that are fundamental to the field of geography as a whole.

In my talk, I will briefly review the general capabilities that all large GISs must have to adequately perform their intended function and the research issues that arise from this. I will then describe aspects of the field of AI and how they relate to these issues. I will conclude with some additional issues that arise from the application of AI techniques in GISs.

Current Context

The large, multi-purpose GIS is a natural next-step from the previous era in GISs. For fifteen to twenty years after construction of the first GIS, building and maintaining a geographic database required a level of manual effort and expense that would quickly dominate the entire system as the size of the desired database grew. GISs have thus historically fallen into one of two categories: (1) those intended to cover a large geographic area with emphasis on input and data maintenance capabilities, and (2) those with greater emphasis on analytical capabilities and are geared toward geographically smaller areas (e.g., municipalities). The state of data input technology was thus seen for a long time as the major obstacle to the realization of systems with both a large data base and sophisticated analytical capabilities. The availability of automated data capture devices and the streamlining of data input procedures has now largely overcome this as an overriding bottleneck to large geographic database systems.

In order to provide both the database management and analytical capabilities now envisioned efficiently and with

reliable results, a GIS must be able to provide all of the following capabilities within a single environment:

(1) contain many layers of data of different types, where each layer itself may be very large,

(2) be capable of solving a large array of different problems, some of which may not have been anticipated by the systems designers as the system grows and changes over time, and (of course),

(3) provide quick interactive response.

Toward this goal, however, GISs have consistently exhibited severe problems with response times and storage volumes for data sets of any significant size, as well as with rigidity and narrowness in their range of applications. Efficiency problems seem to be difficult to predict and are often not discovered until after a substantial investment of time and money has been made. (It is unfortunate for others that negative outcomes of what can be looked upon as empirical experiments are rarely published). Existing GIS technology requires operation on a predefined data set with "built-in" objects and relationships. This is a particular problem when different people or applications have differing conceptual views of the same phenomenon.

All of this is in spite of the fact that many new algorithms have been developed for specific analysis and manipulation procedures that had been recognized as bottlenecks to overall efficiency, such as vector overlay. There has also been much activity in the development and analysis of methods for efficiently representing geographic data. This has included a debate over the past ten years as to whether raster-, vector-, or hybrid-type data structures are the best approach for large, multipurpose systems [Peuquet, 1979; Chrisman, 1987]. Techniques and concepts from other fields such as Data Base Management Systems (DBMS) and Image Processing have been directly applied in individual implementations [Samet, 1984; Van Roessel, 1986].

In retrospect, all of these efforts have been centered on narrowly-focused implementational issues with no clear view or overall insights toward solving what we now recognize as a very fundamental problem of our lack of a formalism for representing geographic knowledge. Without this, we cannot systematically construct representations of geographic space and how entities interact in a computer context with any degree of flexibility or reliability, particularly when dealing with multiple application contexts. This realization also means that our entire approach in the future development of GIS technology must change. Our lack of understanding of geographic space was also realized twenty years ago in the context of the quantitative revolution as was reflected in work by Bunge, Berry, Nystuen, and others in the late sixties and early seventies as they attempted to develop

a generalized representation of geographic space in order to find commonalities among various geographic theories. Their ideas, however, never advanced beyond an initial and very general state of development. This can in part be attributed to a lack of the proper tools for doing so.

In the following discussion, I will try to show how the tools and concepts developed within the area known as Artificial Intelligence can serve two important functions. On an immediate and practical level, one is to provide some very powerful implementation tools to aid GIS efficiency and flexibility. In the longer term, AI holds much promise in helping to address the most fundamental and theoretical issue in geography, the development of a formalism for representing geographic knowledge.

ISSUES IN GIS RESEARCH

The shortcomings of current GISs in the areas of efficiency and flexibility are related to three special characteristics of geographic data which are not shared with other types of two- or three-dimensional data. First, geographic entities (e.g., lakes, cities) tend to have convoluted and irregular boundaries. They thus do not lend themselves to compact definition and quickly become extremely large. Second, spatial relationships between entities tend to be imprecise and application-specific, and the number of possible spatial interrelationships is very large. Third, the definitions of these objects tend to be inexact and context-dependant (e.g., State College, PA, may be a city to some who live there, but not to most others). This also means that definitions of objects can change over time with changing applications.

In order to satisfy these requirements, the following facilities seem essential in any large, multi-purpose GIS:

(1) a highly flexible, robust and efficient method for data representation that can deal with inexactness,

(2) non-exhaustive database search procedures,

(3) automatic error-checking and indications evaluation of data quality,

(4) a robust set of spatial operators that can handle inexactness and an algebra for combining them in complex ways to provide flexible and efficient retrieval, and

(5) the capacity to automatically acquire and store additional information derived through responding to user queries (i.e., to learn).

In order to deal with inexact and varying entity definitions

and relationships, higher-level knowledge concerning the entities being represented and the relationships between them needs to be built into the database. Such knowledge would be used to make "judgement calls" for specific cases. This would obviate the current need to insert artificial precision into the data. It would allow a more natural data representation while allowing varying definitions for specific applications contexts. Such knowledge can also be used as a self-checking mechanism to detect and potentially correct data errors.

Non-exhaustive search procedures involve the use of shortcuts or heuristics to greatly increase data retrieval speed by eliminating large portions of the database from consideration at an early state of the search process. Heuristics utilize built-in data about the data--i.e., knowledge about how the various data elements are distributed within the database.

The system would also use higher-level knowledge to effectively narrow down the problems search space with respect to: (1) data retrieved from the large geographic database, and (2) activation of GIS operations on the data retrieved.

A spatial relational algebra would allow the system to answer user queries concerning the relationships of complex objects in a large landscape where the specific query or application cannot be anticipated by (i.e., built into) the system. This flexibility would not only greatly extend the types of data and range of applications a single system could handle, it would extend the useful life of a system for a given application as needs grow and change over time.

The capacity to learn is the most powerful means of dealing with imprecision and uncertainty. This allows a system to provide answers in terms of confidence margins and to adapt to new kinds of queries and applications.

Increasing complexity of the database and broadening of analytical capabilities also imply that ease of use must also become an increasingly important concern. If a large, complex GIS is to be a useful analytical or decision-making tool, it must represent and utilize information in some manner that coincides with human representations of space and human approaches to problem-solving. Very large, general-purpose GISs will certainly require significant advances in all of the above areas.

Besides helping to overcome these existing major shortcomings in GIS technology, the application of the results of recent AI research on learning may have a profound impact on the field of geography as a whole, since learning procedures could be built into a GIS for the purpose of adapting to the imprecise and voluminous nature of geographic data as the system acquires knowledge about the phenomenon. This means that such a system can be used to acquire new knowledge concerning the nature of geographic phenomena and their interrelationships.

RELEVANCE OF THE FIELD OF AI TO GIS RESEARCH

Overview of AI

Artificial Intelligence is a broadly-defined field of study that encompasses computational techniques for performing tasks that exhibit the characteristics we associate with intelligence in human behavior--understanding language, learning, reasoning, and solving problems. This includes a wide range of applications that in some cases have become sub-disciplines in their own right. These include computer vision and expert systems. Computer vision involves how to make computers "see" in the sense of comprehending visual input, and Expert Systems involve solving a specific class of problems as a human expert in a given area would solve them.

Another area of application sometimes confused with Expert Systems is what may be called Intelligent Database Systems. These latter systems do not incorporate the highly domain-specific, higher level information that would charact rize the knowledge of a human "expert." They instead emphasize the handling of large, complex collections of data by utilizing information about how the data are organized and the characteristics of the data for performing efficient and flexible search and retrieval. It is also used for performing integrity checks on the data. Expert Systems also stress analytical power and to date are typically much more limited in their data handling capacity.

Artificial Intelligence is thus a technology of information processing concerned with inexact and incomplete knowledge, reasoning, learning and perception. There is a dual purpose to this overall field of study. The first is to enable computers to perform tasks requiring intelligence. The second is to use the computer as a tool for increasing man's understanding of intelligence, i.e., the nature of the learning, reasoning, and problem-solving process, as well as the conceptual representation of knowledge within the human mind. Within the field of geography, this means that AI is both a practical and theoretical tool. On the practical side, it offers strategies and techniques for greatly increasing the range, size, and complexity of geographic applications that can be economically handled in an automated context, thereby overcoming many severe performance limitations currently being experienced with geographic information systems and other spatial database systems. On the theoretical side, the field of AI offers an approach for better understanding geographic space and geographic processes, (a) by providing a new and systematic approach, and (b) by providing a new methodology for testing and verifying even non-mathematical theories concerning complex, real-world processes via automated means.

Much of AI is thus concerned with the design and understanding of knowledge representation schemes. How can knowledge be represented so that it (a) can be easily used in reasoning, (b) can be easily examined and updated, and (c) can be easily judged as relevant or irrelevant to particular problems? Search is a key issue. It is usually easy to invent brute-force or exhaustive algorithms to solve problems, but they fail in real-world situations where there is typically an extremely large volume of various types of information to be examined. This approach is obviously not how the human memory functions and has proven impractical for computerized databases even in situations where hardware capacity can be assumed to be unlimited. An understanding of non-exhaustive search techniques can help us to avoid the "combinatorial explosion" that swamps brute-force attempts in many current applications of computing to geographic problem solving tasks.

In reasoning and learning, particularly with incomplete and inexact information, inference is also a key issue. Inference is the process of creating explicit representations of information from implicit ones. It can be viewed as the creation of knowledge itself. Deductive inference proceeds from a set of assumptions called axioms to new statements that are logically implied by the axioms. Inductive inference typically starts with a set of facts, features, or observations, and it produces generalizations, descriptions, and rules which account for the given information and which may have the power to predict new facts, features, or observations.

Fundamental issues of Artificial Intelligence thus involve knowledge representation, heuristic search, perception, and inference. The field of AI currently consists mostly of a collection of programming techniques for performing these tasks. These techniques allow knowledge to be represented in many forms: collections of logical assertions, heuristic rules, procedures, statistical correlations, etc. The activity of developing "intelligent" computer systems employs proven mathematical principles, empirical results of real-world observation, experience from previous implementations, and heuristic, pragmatic programming techniques.

A mathematical approach to modeling many geographic processes implies a determinism and a closed environment that is usually not representative of reality. The tools of AI provide additional methods for non-mathematical reasoning, including inexact "rules of thumb" for application in problem solving and modeling.

While the intellectual challenge to investigators in the area of what we now call Artificial Intelligence has been in existence for centuries, it is only very recently that a glint of practical feasibility has shown on a wide variety of applications. AI as a field began in the 1950's with attempts to develop computer programs that would solve problems involving

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non-numeric reasoning. It was soon discovered, however, that the number of steps required for formally specifying this type of reasoning for solving a problem of any level of complexity was an extremely difficult task. During the early and mid-1960s, overly ambitious projects in automatic English/Russian translation not only failed to produce the promised systems, but dampened respect and enthusiasm for AI as a field.

Today, however, the field has recovered. Many scientists, engineers, and programmers are studying AI techniques and building AI systems. The pendulum may have swung back too far. Amidst the current excitement about recent successes of AI, some voices are making claims that cannot be substantiated. How AI techniques can be productively utilized for advancing GIS technology and the benefits that can be expected must therefore be very judiciously evaluated.

Research in GIS Involving AI Techniques

Given the current excitement in the use of AI techniques, there have been many recent applications within the computerized spatial data handling context. Most of these so far have been expert systems that are geared toward performing specific tasks such as terrain analysis and cartographic design. Some of these represent direct application or extensions of pre-existing systems or general-purpose "shells" that were designed and implemented for a different type of application. All of these systems are limited in their problem-solving power and primarily serve to demonstrate the lack of formalized knowledge in these areas and the difficulties in developing such knowledge. Examples of existing geographic expert systems include Autonap and Map-Aid for map design [Freeman & Ahn, 1984; Robinson & Jackson, 1985] and ACRONYM and MAPS for terrain analysis [Brooks, 1983; McKeown, 1983].

A few recent Intelligent Spatial Database systems of interest have been developed. These to date should also be characterized as research prototypes, with these experiences simultaneously revealing promise and new problems. Such systems have emphasized rapid spatial search and the development of a spatial algebra to allow complex and flexible query structures. These include KBGIS II, Lobster, and GeoKnowledge [Smith, et al., 1987; Frank, 1984; Peuquet, 1987]. Lobster features an intelligent user interface to a more traditional database management system. KBGIS II and GeoKnowledge were designed and built with AI techniques fully integrated into the system design. These efforts have revealed shortcomings of AI techniques in the GIS context. This includes both concepts and implementational tools. For example, search techniques within the realm of AI are generally geared toward finding "the" result as a single entity, where in geographic search it is usual that many entities must be retrieved to satisfy a query. AI implementational tools also tend to be geared toward what within a GIS would be considered small or very simple problems. For example, the LISP language

always assumed until recently that the entire data space for a particular session resides in central memory. It must be emphasized here that these are not intrinsic shortcomings but merely reveal that AI as a field is still in an early state of development.

CONCLUSIONS

There are a number of fundamental shortcomings of GIS technology that must be solved, and the field of AI seems to offer a number of powerful techniques for overcoming them. Enhanced capabilities have already been demonstrated for specific tasks. These initial efforts have also revealed other factors that must be kept in mind. The first is that the application of AI techniques is not going to be an instant fix to the current performance shortcomings of GIS technology. Second, AI techniques can (and perhaps in other cases cannot) be fruitfully used in GISs. The third, and perhaps most important, is that links with researchers within the field of AI must be initiated and maintained to allow a more interdisciplinary approach in the development of GISs.

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Geographical Information Systems: Research Needs in Spatial Statistics

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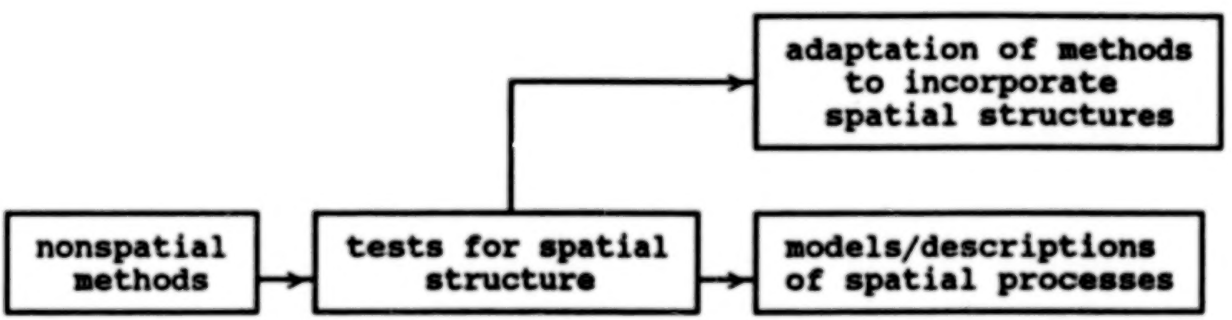
Abstract. As Geographical Information Systems expand, greater use will be made of statistical analysis for data checking, data synthesis, model generation, and hypothesis testing. Many of these procedures will have a spatial dimension; new developments in several areas will be required if the availability of comprehensive GIS's is to be exploited. Such directions for research are outlined in this paper.

INTRODUCTION

There is a view, perhaps more common among physical scientists, that Statistics is only needed when insufficient data have been collected. This would suggest that, as our data-collecting capacity expands, statistical analysis should become less and less necessary. Such a view is dead wrong! Conceptually, knowledge advances by building models which enable us to extract the essence from complex processes; statistical analysis is an essential component in these developments.

In order to develop a research agenda, let me first present a brief personal view of developments over the past twenty years. My own involvement in geographical modeling began in the late sixties at conferences in London organized by the Regional Science Association and by the Commission on Quantitative Methods of the IGU. The RSA conference included papers by Clive Granger (1969) and by Andrew Cliff and myself (Cliff and Ord, 1969),

which presented initial ideas on spatial modeling. At the IGU conference the following year, there was a lively session in which Peter Gould (1970) presented a powerful critique of the use of nonspatial methods for spatial data analysis; in Nick Chrisman's terms, the danger of relying exclusively upon imports; Andrew Cliff and I again joined in the fun (Cliff and Ord, 1970). Thus, these conferences served to identify future research directions (though this was by no means the only source of such ideas) as illustrated by the following diagram:



Another theme in Peter Gould's paper was the question of whether quantitative geography should be concerned with formal inferential procedures or more with empirical modeling in the Hägerstrand tradition. It seems to me that the answer is yes--formal inference is appropriate in more experimental settings, whereas a more data-analytic and case-specific approach is appropriate in others depending on the objectives in hand.

In terms of objectives, a variety of considerations exist:

objectives: (i) checking, descriptive or inferential
(ii) smoothing, prediction or causal explanation

In turn, a variety of other considerations must be borne in mind:

data base: cross-sectional (static) or spatio-temporal (dynamic)

scale:	local or global
variables:	continuous, categorical or point process
spatial structure:	grid, irregular sites (aggregated) or continuous in space
process structure:	(locally) linear or intrinsically nonlinear.

Not all combinations in this list make sense, and others are trivial, but let me explore a few of the possibilities that have been developed and bear further examination.

DATA CHECKING

Data-logging devices, be they on-line digital recorders or satellite pictures, generate data far faster than we can examine it. But such data can be contaminated. For example, when a patient moves during an operation, this produces a false signal on a variety of scanning devices. The first need for statistical analysis then is to check the data records and to ensure that data are accurate. This is not purely a problem for spatial data, but is an important problem to be faced for any information system. Indeed, several data-checking methods are closely related to techniques for image processing. Some of these techniques are discussed in the section on descriptive methods. We need to understand how such methods perform in a variety of settings as well as to develop efficient computational procedures.

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INFERENTIAL METHODS

Inferential models for static processes

This field has been explored fairly extensively with regard to:

linear models:	Besag (1976), Ord (1975), Haining (1978), Doreian (1982), Griffith (1987)
covariance models: (kriging)	Matheron (1971), Journel (1977), Mardia and Marshall (1984)

Extensions include allowing for missing values and the incorporation of regression structure.

The computational restrictions inhibiting the use of maximum likelihood methods are now quite well understood and the main future challenge lies in developing locally effective estimation procedures such as Besag's pseudo-maximum likelihood or conditional least squares (e.g., Lele and Ord, 1986).

Inferential models for dynamic processes

This area includes the work of Bennett (1979) on spatial time series, the spatially and temporally stationary process models of Aroian (1980) and Pfeiffer and Deutsch (1980) as well as more recent work on spatial econometrics (Anselin, 1986).

In this area my feeling is that we need to avoid going down the track of contemporaneous simultaneous equations models which has bedevilled applied econometrics. Rather a causal chain approach should be used (cf. Cliff et al., 1985); the evidence appears to suggest that capturing local spatial structure in individual equations is more important than a large

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interdependent system with a naive error structure. The extension of transfer function modeling to include spatial components would seem a major direction here.

Categorical and nonlinear models

Nonlinear regression has developed rapidly in recent years (e.g., Gallant, 1987). For intrinsically nonlinear processes such as gravity or dissipative structure models, nonlinear regression with a spatial dimension will become a vital tool as data bases improve. Similar comments apply when the dependent variable is categorical and logistic or similar models must be used.

DESCRIPTIVE METHODS

Cressie (1986) has developed a robust method of kriging which enables the data analyst to avoid problems with outliers, to separate different spatial scales and, at the same time, to avoid many of the numerical complexities faced by "optimal" methods. The spatial adaptive filtering methods of Foster and Gorr (1986) allow similar flexibility in dynamic analysis.

These methods appear to work well, but their properties are less than fully understood. We need to evaluate such procedures more fully and to determine their effectiveness and limitations.

Besag's (1986) work on image enhancement using local structural properties is in this same general spirit, and similar comments apply.

This work shows the increasing extent to which checking, descriptive and inferential procedures are likely to draw together in the operation of GIS.

POINT PROCESSES

Inferential models

The earlier work by Rodgers (1974) on quadrant counts and Bartlett (1975) and others on doubly stochastic processes seems to have stalled somewhat; local models such as those developed by Diggle and Grattan (1984) deserve fuller exploration for both descriptive and inferential purposes. For a general review, see Ord (1986).

Descriptive methods

The p and K functions developed by Ripley (1977, 1981) have superseded earlier nearest neighbor type methods; these are effective in detecting departures from the random (or Poisson) assumption but have, so far, been less useful in suggesting alternative methods. It would be nice to contemplate a model identification procedure which could use such functions to suggest basic model structures.

Dynamic point-process models

An area which is largely unexplored is that of dynamic point process models where we can envisage a system of births and deaths over time. Work thus far has been highly aggregated and mainly applied to epidemiological processes, but there remains a lot of scope for more micro-level studies. High resolution (both space and time) data bases are clearly a prerequisite

for empirical work in such studies, and the area of medical geography may offer the greatest potential for such studies (cf. Cliff et al., 1985).

CONCLUSIONS

Improved geographical information systems, greater computing capacity, and better statistical software lead to new challenges in statistical modeling for spatial processes, many of which will involve a move from data-poor to data-rich or even data-glut environments. A variety of new statistical procedures will be required if we are to tap the information which new, large data bases can provide.

In this overview, I have concentrated upon the more directly statistical problems, but one can expand the framework to consider process control; the information systems now becoming available will allow the logical sequence of modeling, prediction, and control to be explored more comprehensively than was even considered possible a few years ago.

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PLENARY SESSION 5. GEOGRAPHIC INFORMATION SYSTEMS MANAGEMENT AND IMPLEMENTATION

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PLENARY 5

GEOGRAPHIC INFORMATION SYSTEMS MANAGEMENT AND IMPLEMENTATION

CHAIR: William J. Craig, University of Minnesota

PANEL: John Scoggins, John Scoggins & Associates
John C. Antenucci, Plangraphics, Inc.
Paul Tessar, Minnesota Planning Agency
Bernard J. Niemann, University of Wisconsin/Madison

William J. Craig:

The title of this panel is "Geographic Information Systems Management and Implementation." By its nature, we are talking about the real world of existing users and potential users of GIS technology.

I would like to make a statement of my own of what should be the research agenda for a national GIS center. This statement is not personal but grows out of URISA's (the Urban and Regional Information Systems Association) strategic plan which calls for a formal statement of the association's research agenda. Two weeks ago a seven-member group, URISA's research advisory committee, met to draft this agenda. I will summarize this discussion under five major headings.

First, GIS development should match user needs. Second, potential users need good descriptions of GIS capabilities and shortcomings. Third, data is the fuel that drives the GIS engine; R&D is necessary to define the data delivery system. Fourth, as GIS technology becomes more diffused, management issues become more profound. Fifth, work is needed to fit GIS technology into corporate management and decision making processes.

First is the issue of development fitting needs. For states, counties, and cities, GISs, like other technology, will be embraced only to the extent that it helps them do their jobs better. We would argue that the GIS research agenda has already been articulated by frustrated users. They would like to show their city councils where public monies have been spent over the past five years and which locations have responded with improved neighborhood quality. They would like to summarize county assessor records across the state in order to update statewide land use maps. Current GIS technology is too limited in what it can do. We would argue for a research agenda that is explicitly driven by application needs not by the research interests of the scientific community. Heresy.

Second, as users and potential users, we would hope that the national center would strive to describe current technology and its applications so that we can better know what to buy. The

existing written record on GISs is thin and fugitive. We would like to know who has installed which GIS for what purpose so that we can network with those that have similar needs. We would like to see system descriptions and benchmarks. We would like to see research on comparative systems, both installations and software. We would like to see research on what Vince Robinson calls "domain sensitivity." To what extent have local decisions on such factors as data structure and scale limited the usefulness of those systems? And we would love to read the book describing GIS failures and the reasons behind them.

Third, we see data issues as preeminently important and are deeply concerned that this topic is not in the NSF agenda. In this way, we are much like the federal government users represented in the opening plenary on Monday. The cheapest way to get good up-to-date data is from the administrative records of government. Often, all that is needed is to add a geocode to each record to make it a useful part of a GIS. For example, a data file of building permits issued in the past year presented in map form is a powerful statement. The combination of several data files can produce a synergism where the understanding provided is much greater than the sum of the individual parts. Borchert argued a decade ago that the theoretical development of the science of geography had stopped because of a lack of such summary data to stimulate theoretical thinking and test hypotheses.

Research and development is needed in many areas to help develop these and other data sources. Data standards are needed. Automated scanning of maps can be further developed. Models are needed to help define which departments and levels of government should capture which data. Gaining intergovernmental and intragovernmental cooperation remains a political problem in most places. Legal responsibilities for data, public access, and pricing strategies are unresolved and frustrate data sharing. Problems of generalization arising from combining data captured at different scales also need to be addressed. One would hope that the National GIS Center would develop good translation packages to communicate data among different GISs.

Fourth are management issues. I will address only three. I have already alluded to the first, the intergovernmental problem of coordinating data flows among many departments, agencies, and levels of government. Second, this problem is exacerbated by the proliferation of computers (especially many powerful micros not involved in a network) and incompatible GISs. Finally, we have the management problem of storing, indexing, and accessing ever-expanding masses of data. Research in the areas of both technology and organizational theory are required on these issues which I term "management problems." Finally, I come to the bottom line: how can GIS technology be useful in the corporate management and decision-making process? Clearly, we need to move to the point where every GIS product does <u>not</u> require the effort of a full-blown research project. We need some software layering

to move the user interface above its current level, which is roughly equivalent to programming in FORTRAN if not assembly code. And we need a system which incorporates artificial intelligence so that novice users like mayors and county board members can gain the full power of GIS technology.

This is a summary of URISA's statement of what the GIS user community wants from a national center for geographic information and analysis.

Technology is Not a Problem. **John Scoggins:**

From what I've heard about GIS during the last two days that I have been here, are words that I think made Webster flip a couple of times because I don't think he recognized them. In my dealings with geosystems I thought a centroid (?) was the first cousin of an astroid. I will be discussing GISs as a practitioner, from the user end. I'm one of those individuals who has to account to the taxpayer as to why a million dollars was spent for GISs.

Also, I have a consulting company that specializes in assisting local governments in meeting their computer technology or information management needs. I've been in public administration for 35 years, 23 at the federal level, 8 at the state level, and the last 4 at the local level.

What I've heard in the last two days reminds me of the debates that have been going on about trade barriers and isolationism. What I've been hearing is that GISs are isolating themselves; they're talking about GISs not being an intergal part of our organization needs, if you will. Looking at it from my perspective sitting at the county courthouse or the city hall, a GIS is just another system that's competing for the resources of the organization. What I see as the major problem of GISs, and this was brought up yesterday very succinctly by the gentleman from the Land Management Bureau, is that we don't know how to market the results of our research. Even though the use of GISs is exploding, I think the horror stories are going to start catching up with the implementations that are going on, and we're going to have a period of time when GIS growth will come to a halt. So I think the GIS environment, the industry, or whatever you want to refer to it as, i.e., the academic, the vendors, everyone involved in it, is going to have to start doing some PR and some marketing. That doesn't necessarily mean selling but marketing and educating.

What I'd like to discuss with you today is computer technology use based upon my research in the last eight or ten years, the most recent of which was finished as of 1 January 1986. What's going on in local government? What are GISs competing with? I'm going to address some management issues and computer technology in local government to reaffirm that

Technology Is Not A Problem.

When Will called me, he had read my summary of the survey that I'd done in conjunction with the International City Management Association to determine exactly what is the current status of computer technology in local government from a market viewpoint. I do a lot of consulting to major computer vendors on the local government marketplace, and this was part of that consulting. To give you an idea of the comprehensiveness of the survey, let's look at the survey universe and, as we go through this, some things that are significant to all of us who are involved.

Total universe--3,200 cities and counties, with usable returns of 1,032. One of the things that was interesting and that we're going to talk about a little later is the trends that are occurring in local government. (The results of the survey are published in the ICMA municipal year book, 1986, pp. 33-45.) We surveyed one-third of the cities and counties with populations between 10,000 and 25,000. We surveyed all cities and counties over 25,000. Who responded to the comprehensive survey that was sent out by ICMA? Non-technical positions were 49 percent of the respondents to the survey, which said that they were basically in charge of computer technology in the city or county for which they were responding. How comprehensive is the use of computer technologies in city/county governments? Eighty-eight percent have an in-house system, and we're not talking about having a micro. In my survey, I defined central systems as a mini or a mainframe that had multiple users, basically more than five. Eighty-eight percent had what we called the central system in the organization, 9 percent had some joint cooperative effort, and only 3 percent had no computer support.

What does this mean to those who are looking at the market place? It means that basically there are no virgins out there, if you will excuse the term. What we're in is a replacement environment in local governments. Some cities and counties are on their fifth system. They're in their fifth generation of computer technology in that organization, and we would hope as they go through each generation, that they're going to improve their knowledge, their ability to use the technology, and that their demands are going to be much greater than on the previous system. So there are very few local governments with no computer support. The entire 3 percent was comprised of jurisdictions with a population below 25,000.

One of the things that I've done over the years with my surveys was to come up with three major categories of systems that local governments use. The first is office administration support. Every organization has office administration systems, those fuctions that every office has to do to get its work done. The second is organizational administrative support. These are the systems that support the infrastructure of the organization, whether it's a city or a county. This includes finance,

personnel payroll, fleet management, facility management, those functions that keep the organization going. The third area, service and operational systems, I call a mission critical because this is the only area where the taxpayer comes in contact with the expenditure of funds that buys the computer technology. This includes police, fire, public works, parks and recreation.

Where do geosystems fall in this area? It can be one, two, or three, depending on how it's being used. It is certain that if GISs are not more incorporated, and I'll come back to this later, into item number three, the mission critical systems, i.e., providing more support to the operational functions that the taxpayer comes in contact with, we're going to see a major decline in the implementation of GISs in local government.

Let's look at who has the shares of the market out there. This tells us something because I'm going to come back and talk about trends in a minute. Big blue still has 39 percent of the local government marketplace. I broke it down based upon IBM's different technologies, i.e., the System 36, System 38, and 4300 Series. This was before we had the Power of 2, Burroughs and Sperry (UNISYS). But Wang, DEC, Prime, etc., are the areas where we're seeing the major growth of computer technology in local government. And again, when we look at future trends, we're going to see this continue.

When we look at micros, who has the share when we're just talking about hardware vendors? I found 48 different manufacturers of micros being used in local government. The largest user, a city of 400,000, had 510 micros that they were using. Most of them were in the stand-alone mode.

What are the means of program development and maintenance? How are they supporting their current applications? We're talking about new technology, we're talking about GISs, and I hear all these terms of satellite imaging and everything, but you look at what's going on at the user level, and we're still doing things like we were doing 15 years ago. The only good thing that I see is the new application software development tools. Someone yesterday mentioned non-procedural languages; this chart shows us that 34 percent are getting out of the traditional structured Cobol-RP6 language environment to do things. This type change is going to increase tremendously.

Almost half the cities and counties are saying that they're acquiring their software support from outside the organization. We're getting away from the traditional in-house support and going to third parties. And we'll see why in a few minutes.

Let's look at some trends that are occurring in the local government marketplace. This survey in combination with Ken Kramer at the University of California at Irvine that deals in policy helps identify the changes that are occurring. We can see the shift in vendors in the market place. They're shifting

away from the traditional mainframe environment. They're shifting to "the mini computer," micro-computer environment.

Next we can see that multiple systems are becoming common place. Twenty-four percent have at least two central systems. I'm going to show you a slide in a minute that's going to shock you when it comes to the number of systems a local government may have.

The micro computer explosion was from 1983 to 1985 (over 800 percent growth rate). Does anyone have any idea why we had the explosion of micros in local government during that period of time? We had a void, and any time you have a void, something's going to fill it. We had a void in the area of office administration, to use the other term, office automation, document preparation, spread sheets; and the traditional mini and mainframe environment could not satisfy the users' requirements. So what did they do? They turned to the micro computer because they could solve their OA problems with the micro computer. The major increase of micro computers in local government has leveled out. We've reached the plateau. It'll be mostly a replacement market, and as we get more intelligent terminals, and, as we get different types of OA functional software on minis and mainframes, I eventually see a decline in the number of micro computers in local government across the board because the void is no longer there. We can have integration without all the problems of networking.

Attitudes of people are very important in this business. Two questions that the survey asks: Would you consider changing your hardware vendor and would you consider changing your software language? The bigger the organization, the more willing they are to change, which tells us that users are not happy with what they've got. It also tells us that the name on the box is immaterial. Someone said this morning, "Hardware is becoming transparent to the user. They don't care if it's an IBM or Burroughs. The user is after results."

So that's a major trend. We have users out there who are finally realizing that the success of the system is not determined by the name on the box or the amount of money spent.

I'd like to show you a comparative analyses of similar size organizations. One of the things that we make assumptions about is that the size of an organization necessarily would indicate its level of sophistication and its level of satisfaction. This is a county in the upper Midwest that has two systems and 47 users. The second system is a city of similar size (800,000 population). It has 21 systems with 1,300 users.

Neither organization has users that are happy with what they have. When we looked at departments within the organization, not one department was happy with what they were getting out of all that hardware. One organization had three GISs operating in it

on three different hardware vendors, and none of them talked to each other. That's a problem that has to be addressed by providers of GISs.

This is kind of an overview of what's out there. What is the marketplace that you're involved in? Let's look at GISs as they relate to what's out there. In my survey, different parts of the country reflected different applications. I identified basically 62 or 65 different applications that local governments use. GISs were identified in three major areas--land records management, engineering, and planning and zoning. This is what we found out there. CS means they were doing it on the central system, the mini computer or the mainframe computer. Engineering was basically CAD CAM, design and mapping. Planning and zoning were the only places we used the word geoprocessing. In land records management we used the term digitizing. The following question was asked, what do you plan to do in GISs during the next three to four years, and what do you plan to do it on? Users are moving faster than the survey results indicate. Again, by doing follow-up telephone calls with the random sampling of the universe, I found that they're moving much faster than they had planned in the area of GISs.

The survey says everyone has plenty of hardware. There are plenty of systems. What are the major problems that local governments have with computer technology? When I began my talk I said that technology is not a problem. Sixty percent of users have moderate to severe problems on central, including shortage of technical staff, inadequate training of staff, inexperience of technical staff, application software bugs, and failures. If you've got problems with the first three, there's no way that you can escape problems with the fourth. Hardware reliability: only 9 percent said that's a moderate to severe problem. In most cases, their system was under capacity based upon their current needs. The problems listed above are not technical problems. They're not computer technology problems. They're management problems. The lack of understanding of requirements for technical staffing in city/county government is a serious problem. How can you pay a technical person $35,000, or $45,000, or $50,000 when the department heads are making only $25,000-$35,000? Local governments cannot compete in the marketplace. So they really can't solve those problems under the current organizational constraints that we find in city/county government. They cannot solve those problems, so they're going to have to look outside the organization for the solution to those problems. When it comes to GISs, those problems are just as real as they are in financial management, public works, and Computer-Aided Dispatch systems. So these are some of the problems that this research agenda is going to have to address. How can we help those local governments? The same problems exist at the state level in relation to technical staff.

Last, I'd like to use a slide that I used when I was talking to vendors in marketing seminars for vendors. What are future

trends? All future markets will be application software driven. Sixty-five percent of local governments said they were going to acquire in the next three years all of their application software outside the organization either through contract for development or packages. They want solutions. That's the number one requirement of cities and counties. More users are involved in system selection. What is the hardware vendors' role? They must provide total solutions. Three years ago, if you went to Wang or you went to Prime or you went to one of the major vendors, do you know how many people they'd have on their corporate staff that were knowledgeable about GIS geoprocessing? Basically zero. And some of them now have as many as five or six people on their staff that specialize in GISs at the federal, state, and local government level. They recognize it as one of the seven top vertical markets in the United States when it comes to marketing their hardware, so there's going to be a major marketing effort for GISs.

What are GISs going to be competing with for the user's dollars? The four big ones. And two of them, in fact three of them, are mutually supporting because all three of them are very dependent on GIS or GIS-related type of information. They are law enforcement; the number one selling package in the marketplace today is CAD, Computer-Aided Dispatch, which if it is a good CAD system must have a good geobase. It must have a good premise file, which is locational information.

One of the things that we have to do as GIS experts is to learn to communicate with the end users in a language they understand. One of my clients in a very large county in Wisconsin was one of the county supervisors. He was going to make the decision of whether to sign the check, buy the system. After three hours of sitting through a GIS demonstration by one of the vendors who is present here, he came out shaking his head, and he stated, "I felt like I was in a foreign country. I didn't understand half of what was said. We just want information about locations. Why don't they call it a location information system and get away from all this other terminology? We want to know if something has ever happened at a location. We want to know if something is happening there now, or we want to know if something is going to happen there in the future. And what are we going to do about it?"

So if there is a message from the user, it is to learn to communicate with us. And this communication only comes through training and education. And if there's any one item that is important on the agenda of this research project it is to develop some processes that will provide for the training, the education, to increase the computer literacy of the user environment in which your products must survive if they're going to continue to benefit the organization for which they were developed.

John Antenucci:

John Scoggins presented some statistics relative to organizational and technological issues that affect the implementation and management of geographic information systems. I agree with him.

What we're really talking about is what is required to accomplish successful implementation and successful management of geoprocessing systems. Today I will address several topics. They will seem to you not to be comprehensive, and they're not intended to be. They may at first seem to be unrelated, but they are. There is a common denominator among the systems existing in Anchorage, Alaska; Albany, Georgia; Sacramento, California; Story County, Iowa; Chester, Pennsylvania; Chesterfield, Virginia; Johnson County, Kansas; New Hartford, Connecticut; and so on. The Knoxvilles, the Spokanes, the Louisvilles, and the Little Rocks, and the common denominator isn't a technological issue any longer.

Successful implementation and management of GISs has over the last ten years or so taken on the traditional role of starting with what has been called a feasibility analysis. There's been a great deal of thought, discussion, and writing about what goes into a feasibility analysis and its role in implementation and design of geographic information systems.

Ten years ago, perhaps only five years ago, there was a great deal of interest in determining the feasibility of the systems with particular emphasis on the hardware and the software as the predecessor on making the decision to proceed with the implementation. Today those organizations and individuals who request a feasibility study to be accomplished as the first step in a successful implementation aren't talking about assessing hardware and software any longer.

We've all heard a lot about the need for improvements of hardware and software, in particular, making it more user friendly and moving into natural languages and the like. I don't mean to discount that, but more and more often we who assess the feasibility of an implementation are dealing with the institutional and financial issues, not the technological issues. There is sufficient technology today on the shelf, in the marketplace, in the universities, and in development to satisfy the needs of many users. We are asked to accomplish the definition of requirements. What that means to the organization from an institutional point of view, from a financial point of view, and from a technological point of view, is separating the needs from the embellishments. What is it that the system will be used to do? What is not available at the moment? And what are the hardware and software, labor resources, procedural resources, institutional support, and other requirements?

The bottom line is that in a feasibility analysis we have

moved away from trying to prove to ourselves and our management that the technology will work. In its stead we attempt to prove that it is required, how it will be used, and how it will be integrated into the day-to-day practices of our organizations.

I have said somewhat humorously in more recent times that the next person I employ will be an organizational psychologist. I really believe that. We need to look at ways of introducing the technology that we have today into the practice of everyday operations of government and the private sector.

A second observation addresses going beyond hardware and software issues, going beyond databases. That may seem like heresy. Not that there is much to be accomplished from a research, development, and from implementation modes relevant to hardware, software, and database issues. But as John Scoggins has alluded to in his study, the technology must become applications driven. The needs must be oriented to applications. How can we automate the environment in which we are working today? That, I believe, falls short of the promise that the technology already offers us. We must move beyond hardware and software considerations. We must move beyond database considerations as a focal point and look at the applications as they address the needs of organizations today.

When I talk about applications, I classify them in three categories. There are cartographic applications in GISs and Automated Mapping/Facility Management, CAD, and the like. They include the production of maps and the production of engineering drawings. They replicate what we do by hand, perhaps with more certainty and consistency, perhaps at a faster pace, and more predictable cost. But they are applications nonetheless.

A second set of applications are oriented to database management. Databases have become a focal point. Database structures have become keenly of interest, e.g., topological structures and object oriented databases.

We can address geographic information systems applications purely in the domain of database applications and ignore the graphics. Conversely, there are times we can almost ignore the database implications and deal only with the graphics.

There is a third area of importance for the research environment. That is the integration of the analytical capabilities of the system as an application area. Analytical applications are widespread. What needs to be accomplished is integration of analytical packages, both manual and automated, into the geographic environment. The electrical industry uses SCADA systems for load analysis. We need to associate them with customer information systems and with the geographic analysis and distribution of power. There are analytical application possibilities in engineering, public works, and finance, among others. Today there is very little that has been done to

integrate the automated analytical applications with automated geographic and mapping systems.

When we perform a requirements analysis, it is the applications that should drive the definition of needs. It is the applications that should drive the database and database structures. It is the applications that should drive the selection of software and hardware. And it is the analytical applications that will bear the greatest fruit, bear the greatest profit and benefit to the organizations which make the investment.

I no longer think it's a question of whether we will implement geographic information systems. It's a question of when. And if we don't implement centralized systems or shared systems, other systems, fragmented systems, will develop as a result of the capabilities and the independence that the personal computer has given us. If we don't move to share data, we will create in a geographic information environment a plethora of independent, unrelated, and unshareable data sets and systems. Shared resources are a key, and to accomplish that leads me to a fourth point, that of education and scheduling. There aren't enough individuals that have the experience to truly implement mapping systems within organizations. Organizations are reaching out, having difficulty obtaining staff that can accomplish the successful implementation of a GIS. There's also a scheduling phenomenon. Organizations have unrealistic expectations of how much time is required to fully implement systems. Ironically, if the systems are successful, you will not be able to answer the question, "is the system done?" in the affirmative. If the system is successful, the database, hardware and software, and applications will only continue to grow. Being realistic about that scheduling is paramount to being able to establish successful systems.

I would like to conclude by discussing a topic that I have taken a great deal of personal interest in lately. I believe it is a key to successful implementation of GISs in both the public and private sector. It gets at the heart of public and private GIS ventures, whether data is shared between and within public agencies or to the private sector. The topic involves the multiple dimensional issues associated with public records and value added information services within public agencies. It continues to require much research in the world of politics and legalities. I believe we need to rethink and redefine our views of what a public record is, and set a framework for arguing that geographic information databases and systems are not equal to public records in all senses of the term. The Freedom of Information Act at the federal level and the information and sunshine acts that have been instituted in many local government levels are archaic and do not represent the growing trend of trying to share data and to share the cost of implementing and operating geographic information systems. Freedom of Information Acts and their allied acts do not deal with a practice that has

become commonplace to many other aspects of government: user charges and cost recovery. The states of Colorado, Kentucky, Kansas, Tennessee, Ohio, and Maryland among others have projects going on at the local level that are entirely dependent upon a successful resolution of the difference between what is a public record and what is not. If geographic information system data is whole or in part considered something other than a public record, we can move more easily to recover the value added by organizing the information in a GIS. The resolution of this issue will serve as the foundation of many institutional issues that John Scoggins' research has pointed out.

In conclusion, there's a crying need to expand beyond the hardware and software issues, moving into the institutional environment. If that move is successful, we must then finance these systems on a continuing basis. And the roots of the financial solution lie in whether public organizations and agencies can support that GIS by the sales and marketing of data.

Paul Tessar:

The Minnesota Land Management Information System, or MLMIS for short, recently celebrated its 20th anniversary as a GIS organization. MLMIS and LMIC, or the Land Management Information Center, has had hundreds of successful GIS applications projects over the years. We've served as a neutral broker of information and GIS technology rather than an involved party, other than on a technical level. We've utilized three generations of hardware and software in providing GIS services to dozens of federal, state, and local agencies. Our system in Minnesota can best be characterized as an interagency, multi-disciplinary GIS center. We're both an outcome of the technology and a facilitator of secondary outcomes.

My talk this afternoon will focus on management and economic issues related to GIS program development and administration using Minnesota as a case example. The research issue behind my thoughts is organizational, management, and fiscal models of GIS institutionalization. The GIS landscape is littered with failures, many because of institutional and financial problems. These topics need to be understood much better if we are serious about seeing the technology implemented and institutionalized.

With that introduction, I've characterized the staffing and equipment requirements of GIS into three distinct types of activities, all of which need to be funded in a GIS production facility: database development, maintenance, and enhancement; systems development, maintenance and enhancement; and applications and production work. All three of these are required for a comprehensive, timely, responsive and cost effective program. How they are funded can have significant effects on the success of GIS institutionalization.

Over the last 20 years, three different approaches have been used in Minnesota to organize and fund our activity. During the initial years of the program, we were part of the University of Minnesota Center for Urban and Regional Affairs. During the recent period, we have been operated as a service bureau within the State Planning Agency. We intend to change the way we do business and become a technical assistance center in the near future.

During our early years, everything was centrally funded. We were a University research shop and the developmental emphasis was on analytic capabilities and statewide databases. The program was a capability development effort which included pilot projects and some limited production activity and application of these. At the time, we felt there was a large latent demand for this sort of analysis and product, but there was a small capacity in the University research-oriented environment, which led to our first evolutionary step into a service bureau.

Currently, we run a fee-for-service organization. Systems operation and management are subsidized, I should add, however, all project expenses, database development, computer charges, staff charges, supplies, and so on must be paid for by users. This has had several unintended consequences. One, and what I feel is probably the most serious, is the decline of database development activities. Our database is aging. Statewide land use, for example, was done with 1968 and 1969 photography. So its currency is in question in some areas. It's also in a grid format rather than a polygon format, and we would like to have more higher resolution data within our Arc Info system.

The basic issue here is that very few users are willing to pay for comprehensive database development. As a result of our business-oriented, market-driven, supply and demand model, the supply of data is aging and becoming much less useful, which is having serious effects on the cost of doing projects and our general competitiveness. Also, we find it difficult to stay up with the state of the practice, particularly in the area of hardware where these devices are relatively expensive. When we buy something, the result is that we end up increasing our computer costs and our computer charges, and that's not a good thing to do. We've also had some problems with project prioritization and what I'll call the treadmill.

In the area of project prioritization, when LMIC was first moved to the State Planning Agency, charging users was seen as a way of limiting demand to only the most important projects. Unfortunately, this has worked a bit too well, and we often find ourselves talking with potential users who have very juicy, interesting, environmentally significant GIS projects but no cash. And we find ourselves sometimes having to say, "Sorry. No ticky, no laundry." And that's not a good position to be in.

Also, we find ourselves having to take on projects that are

somewhat marginal to our main mission, but they have money and we have staff that, perhaps, we need to keep busy, and this has led overall to a loss of control of our program. We're doing what people are able to pay for, not necessarily what is an important project to the state. Many useful, important projects have no budget, and we periodically have excess capacity, and we find this situation somewhat troubling. We do a great deal of valuable work, but we're only scratching the surface. We only do the work where people are well funded.

Along with this whole service bureau notion is the treadmill. We have to cover overheads--data, hardware, software, and project overruns of which we have a number. This leads to increased rates which leads to decreased usage or the mass transit syndrome. We raise our rates 5 percent and lose 10 percent of our computing. Demand is very cyclical. The lows are too low, the highs are too high, and we need to keep our staff busy during those valleys, which further aggravates overhead costs for staffing.

We have a very good professional staff that's very talented, and their specialization is delivering Cadillacs for Yugo prices. Unfortunately, they at least cost the equivalent of an Oldsmobile, but they take pride in doing good work, and it's difficult to tell them not to help out this agency that's trying to preserve that resource. We usually figure out a way to help.

But we try to be philosophical about this. We figure that while we may be losing a little bit on each project, we can make it up in volume.

We also are beginning to develop what we call vendor/client relationships. We find ourselves sitting across the table with lawyers from one of our user agencies in adversarial proceedings negotiating contracts, and this has been somewhat troublesome.

Also, our clients are becoming more businesslike, and they're out there trying to maximize the product they get delivered for cost at the expense of the center. So here's an example of where the collective behavior has an overall negative effect because they're maximizing their projects, and our overrun budget grows.

Also getting clients to pay for product change orders is a problem. Once the contract is signed it comes out that their data really isn't in such good shape, and "can we have these additional maps?" or "could you redo this? You have the colors wrong; I really need to have this one in red." I guess you probably know the problem of trying to deliver a loosely defined product on a fixed price contract. Also, there's a lot of client problems that, when they sign the contract, they expect us to take care of--deadlines, not enough funding, etc. They become our problems, and it's grinding our staff down to a certain extent and affecting morale.

Often clients only appear when their need is a problem, and we call this the bail-out syndrome. Orphan projects on our doorstep and so forth. Also, there's the difficulty of running a business within the government staffing, and civil service procurement, contracting requirements, rate accountability with the department of finance, and the shifting tides of agency management.

Now the bottom line on the treadmill is that environmental planning and resource management are not-for-profit activities. Conserved resources have long-tern environmental benefits, not short-term financial benefits. And I happen to feel, like a number of people at LMIC, that resource management is an important governmental function, and it should be provided with the necessary tools to do the job, one of which is a GIS.

In the near future, we hope to develop a new organizational model for GIS institutionalization in Minnesota, and this is kind of a happy medium between our first two approaches. We call it cooperative endeavors, not fixed price contracts. One of the features of this era will be central funding for the development of the second generation vector based database, also of hardware enhancements and software developments. We feel that these are the ante for a successful, responsive, and cost-effective GIS. If we've learned one thing in the last ten years, it's that it's not enough to build a database once. A continuing commitment in funding is required to make the database continually useful.

In the area of cooperative applications projects, our emphasis is on developing capabilities amongst our users. We will insist that they supply labor for production unless they absolutely have no staff. We will provide them with access to our database, free computing and data storage, and technical assistance in the areas of project design, training, tutoring, production supervision, troubleshooting, and programming supports. The user will pay for dedicated hardware, software, and supply usage, and we will continue to have a small service bureau available for those who have funds but no staff to put into projects.

There's a number of advantages to this approach, and probably the most important is that the user is forced to "take ownership" of his project, and that money is no longer a barrier to doing GIS work. This is especialy important because of ten years of continual 5 percent reductions in agency budgets. They simply do not have discretionary money to purchase services. They do have staff left, however, and those staff are busy trying to do their jobs in whatever way they can, and we would like to help them rather than be inaccessible.

The center at LMIC will provide technical expertise and system capabilities, but again, most importantly, user problems will remain their problems. We're there to help them. We're not

there to do their job for them. We feel that by having users do their own work, they're going to have a better understanding of what it takes to do things, and this will temper unreasonable requests. It will also lead to a better understanding of data, modeling process and analyses. All of this together will lead to more educated, appropriate use of the results of GIS applications. And we also feel that this sort of cooperative approach will lead to more of a sense of GIS community within Minnesota.

What we think the outcome of all this will be is the development of a distributed GIS network in Minnesota with LMIC as the "mother node," the houser of the database and the technical leadership required for such a system to become successful. But we're working very hard to help our users develop their own in-house capabilities in the area of staff, hardware, and software. We intend to serve as an incubation center for new users, and by taking this sort of approach, we feel that data standards, database development goals, integration of data and systems are implicit, bottom up, and built in.

Bernard Niemann:

I'd like to talk about the spectrum of research needs from local and state government and then, as Will suggested, try to put this into some philosophical perspective.

Thinking about this, I studied some literature that begins to discuss the idea of information technologies and social transformation, and I found a National Academy of Engineering Report that was very interesting. The model that I found most intriguing was by a gentleman who works for Bell Labs. He suggests there are a couple of gates that technology has to get through before it's acceptable.

First, there is a technology gate, which I'd like to address later, and there is also a social gate. The author suggests there's a myriad of technologies that are coming. Some will get through the technology gate because of a set of R&D prowess and better base and other factors, but there also has to be a sort of social component. The economics have to be right, as does the public receptivity. And I'd like all of us to think about where GISs and LISs fit into that sort of schema. Where is it on that schema, and where is it likely to run into some infringements?

Taking the idea of the NSF solicitation, which suggests the "fifth bullet," if you will, the social and economic and institutional issues arising from LIS/GIS technology, we start to think about that. One of the components of this technology is graphic display and Mayo lays out another idea: that these technologies have various social impacts. There're niche impacts. There are new domain impacts and killer impacts. There is also niche technology. He gives an analogy using tv. Whereas

everybody thought tv would change the whole sense of media, it really filled the niche. New domain technology refers to something like voice commands for computers, and killer technologies are like the car engine, a technology that basically transforms society. And I'd like us to collectively think of where this GIS/LIS technology is going. What I've done is decomposed the technology into some parts. We might argue about the parts, but this is my little scenario of the parts. We have graphic display. I'm suggesting that the way we do map design and the way we configure maps are going to dramatically change with these technologies, basically transforming the cartographic industry. It's really potentially a killer tool.

Then there's data conversion. We keep hearing that one of the real impediments to these systems is the inability to automate these databases. And the question is, given these various components of data conversion, "Where do they fit into this spectrum?" But I make a distinction between data capture and data conversion because the conversion issue is still a very important one, and we really need to address that.

The other one's a data capture issue, and we've seen air photos transform how we do business. We're starting to see ortho-photography do some of those things and so on and so forth.

Now the one issue I haven't heard much about at this conference is the reference framework. Where are we going to hang these various layers of information? I haven't heard much about that. But one of the components of that technology, that some of us feel is going to re-transform the ability to deal with large-scale databases, is the imposition or the potential of the global positioning satellites. And if we look at the need for geodetic control, we really have potentially a killer technology out there. And the question there is from a societal point of view, "What will the Defense Department do with that technology?" Now there are those that will assert that the Defense Department will no way attempt to block full civilian access to this technology. Well, I'm not so sure, and if we bet our horses on this technology and then the Defense Department decides to turn it off or the shuttle system collapses, what have we gotten ourselves into?

Another issue involves geoprocessing, and the work that I'll be talking a little about is being done in the soil erosion area. It really suggests that we have broken through the technology social gate in some respects. We're really trying to see if, for example, topological overlay is really going to have a societal impact on how we manage natural resources, for example.

How will society adapt to these technologies if we have this sort of faith that people are going to just embrace them? I think the Minnesota example is an interesting one because here they've had a GIS for years, and we still haven't seen a full embracement. Is that a societal problem or a technical problem?

I'm not sure.

Now I'd like to quickly talk about an application. I concur with these folks up here that when we started to look at this particular application, we learned a lot more about the inabilities of LIS and GIS technologies. AG1 60 is a mandated solar ocean plan in Wisconsin. It requires the merger of a couple of records. What I'm leading to is that because of the incorporation of that application, and having studied it in great detail, I'm suggesting that Mayo modify his diagram. As we got ourselves involved with this particular application and mandate, as we moved it towards the societal gate and got it through, we found some sort of inadequacies. We had to sit down and push it back into the technology realm and get some new capacity before it really met the social mandate. It was a push from the technology and a pull from society saying we need some better way to deal with soil erosion. What we suggested wasn't adequate, and we had to go back to the technology and take another look at it.

The law is also very interesting. It requires what I would characterize as the infusion or the integration of the property layer, the cadastral layer, and the resource layer, which you might argue is a merger of the land information community and the GIS community. It quite specifically talks about the requirements in administrative rule. You need to know where the fields are, and who the owners are, and you need the resource parameters.

We took this layered sort of concept with a georeference framework and saw how this would apply to this particular mandate. We used three technologies: computing, positioning, and remote sensing. And we were able to demonstrate that, in fact, we could address the soil erosion mandate as required by Wisconsin's law. This determines who is required to submit soil erosion plans to get certain kinds of farm credits. We also were able to adapt to new federal programs. We were eligible for a conservation reserve program (CRP), and then were able to add those section-by-section databases together to create a county-wide perspective. We showed this county-wide perspective to one of our senator's aides, who helped write the 1985 farm bill. He said, "Oh, my God. That's wicked." And I think for the first time he saw the implications of this policy in terms he could understand. And I think that technology had a lot to do with his understanding of the policy implications.

In numeric terms, you can take 186,000 acres that are eligible for CRP and multiply that by what the farmers are getting to incorporate their lands into CRP today, $800 an acre over a ten-year period. In Dane County alone, over $150 million could be spent by the federal government for CRP lands. Now there isn't that kind of money available, but we're talking about really large sums of money which you could almost argue need legitimate information systems in and of themselves.

The other thing we began to look at is some other policy issues. Because we had the parcel record, we could very quickly determine who owned the land where the erosion was. We found out, because we had zip code access, that most of the land owners whose land is eroding didn't live in Wisconsin. Then we went to the policy makers. Because we were able to integrate the land information side of it with the GIS tools, we were able to gain the policy makers' attention. I began to go down the right-hand side to see why the technology worked. And it worked because of the topological data structure. Now we had some experience in prior applications. The natural sequencing was very interesting. We had the software that Dr. Chrisman brought from Harvard. The GPS system was becoming mature. Landsat was getting specific enough, and when you integrated those things in a sequence, we were able to do this application.

On the inside, I think the most important issue is we had the common good. It was not the issue of efficiency. The common good was that we were starting to see from the politicians' point of view that every landowner was being treated the same. They're much more concerned with the fairness issue than they are with what it costs, to some extent. That's what really intrigued us.

What we learned from this application was that fairness and equity as a democratic process in resource management may be more important than what it cost to implement the system in the first place.

What does that mean to the research community? I'm going to sort of clump these up into some sort of spectrum of the technology side of this question and the social side of this question, again trying to suggest that maybe we need to worry about the social side a little bit more. I think we've already heard a lot of discussion about the codification of terms and concepts. When you think about the language that we've expressed here in the last three or four days, it is mind boggling. And hopefully whenever this Center is established, this debate and the parliamentary process by which we can codify this language will be an essential first step.

This came home to me particularly when I saw a newsletter called "Mapping Awareness" from England, where they went through a long discussion about the differences between LISs and GISs. Supposedly, the applications on the LIS side are land ownership, and on the GIS side they're thematic and resource analysis. AGI 60 suggests "it ain't that way." You have to be able to deal with the ownership layer, and you have to deal with the resource issue. They proceed to make these distinctions, and we don't have time to go through them all. There's a scale difference supposedly, and there's evolved a different set of software for each side of these two continuum. But the newsletter really calls for integration, and I think integration is a very important issue. There is a gentleman whom we sent down to Dane

County to get all the maps and records of his particular parcel of land, and that's what he got. I think seriously that we need research and integration so that we don't continue to perpetuate this sort of chaos.

Looking at some of the other aspects of this research spectrum, I don't know if this is--the theory of incrementalism if there is a potential of such a theory, but what we tend to see is this sort of parachuting into these technologies, and we don't really worry about the sort of institutional, incremental adaption to these technologies. We need people to really think about how we incrementally improve the database and so on.

One of the issues, of course, is "How do we incrementally deal with improving the geodetic framework?" Are we going to wait until we parachute in the ideal geodetic framework and until we go ahead with these systems? I think we're already seeing that's just not going to happen.

So here we have a reference framework starting in Dane County. Should we wait until it's fully complete, or do we slowly start with it and then add data to it? We know very little about what happens when we bring better data into our database.

Regarding data quality research, we've heard a lot of people talk about that. I think the benchmarking issue is really essential to talk about. Dr. Chrisman and some others have talked about truth in labeling and procedural standards and so on. Here we have a new technology called thematic mapper that we basically use to determine the agricultural cover of Dane County. One of the major issues in the 1985 farm bill is "How do you determine what a field is and how reliable is this sensor and how valid is this sensor in detecting fields and boundaries for the 1985 farm bill?" I think a very important issue is the data capture issue, and it also suggests an integration of a couple technologies like remote sensing and LISs/GISs.

We have also worked with detail analysis across large areas. What we've demonstrated in Dane County in our applications is that you need to be able to deal with large areas in very large detailed databases if you're going to meet the legislative mandate and really going to deal successfully with every landowner. You see the same thing starting to happen in Wisconsin when you're dealing with ground water contamination. There is a study done by the Wisconsin Department of Natural Resources using an automative system digitized with the five maps on the side. It created a ground water susceptibility map of about 60,000 legitimate polygons, a massive effort. But because they had it in this format, they were able to flexibly think about what the impacts were, weighing these various maps. This is a very, very important issue in Wisconsin. There is toxification of ground water because of on-site disposal failures, and because of fertilizers in the water. This is a

very hot political issue, and the reliability of this map is a central concern.

Some of the other things we keep hearing about are the cost/benefit kinds of things. One of the other things we discovered from this application that I found very interesting may be a little mundane to the theorists. Steven Chereau, who had a lot to do with the preparation of our soil erosion plan, told me one day, "Well, it cost us about x number of dollars to do a township in Dane County, to do the data collection and do the analysis." And I said, "Well, Steve, what would that cost statewide?" So we extrapolated this out, and we estimated that we could have accomplished the soil erosion plan in Dane County for the whole state for $812,000. Then I went to Jane Licht, who is a member of the Conservation Board, and I said, "Jane, what did DATCAP spend to do the soil erosion plan manually across the state?" Now this is going to sound like this is a real setup, but she said, "About $800,000." So what's really compelling is that we're now seeing parity between manual methods and automated methods. What we need in this Center, I think, are some really good, detailed cost studies that compare what it really costs to do it manually and what it costs with an automated format. Then we can look at the stream of benefits that would accrue.

I think this is beginning to indicate that we are at that threshold, and I think we can now go to the DATCAP folks and say, "Look. Don't tell us you can't afford to do it. You might tell us you don't want to do it for social reasons, but don't tell us economically you can't do it any more."

The last issue I want to talk about is one that everybody knows I'm going to talk about and that's the institutional issues, and it's been something I've been interested in for a long time, ever since we did some work on some behavioral models of land records managers. The Wisconsin Land Records Committee met for two years. One hundred people, ten subcommittees, met for two years and tried to come up with what Wisconsin should be doing in the land information area. What we found out was, when you got down to the bottom line in all of this, it really mattered how, institutionally, you bring these technologies to bear. And that's all this report's about. When you read this report, it's amazing that it really focuses on the institutional aspects. Given all the things it could have talked about, it ended up there. And lo and behold, two months before the report was to go to the governor, the governor lost the election. Now we have the task of convincing the new governor that this is something he ought to be concerned with, so we're back to this political, institutional relationship. We're not very good at it. At least in Wisconsin, we're not very good at it, and I suspect a lot of us are not very good at it. I think we need to spend a lot more time on this particular issue.

Again, I want to suggest that applications are very useful in modifying these sorts of linear ideas, that technology is

going to flow through some technology gate, and then society is going to accept certain elements of that and say, "Thank you very much." There really has to be this thing we all know exists in life, and that is a very large feedback group. And I think this experience in Wisconsin suggests that we need to construct carefully the processes by which we can thoroughly evaluate those feedback groups in great detail.

William Craig:

I think the one summary statement I'd like to make is this: When I began with the notion that I was going to chair this panel and saw that we were listed last on the NSF proposal and criteria and last of the plenary sessions, I thought that we were going to be crying in the wind, that we'd be out here all by ourselves. I think instead from what I've heard over the course of the last three days that there are a lot of people talking about the kinds of things that we've been talking about here today. We perhaps came on pretty strong saying that the applications side is really where it's all at. I don't think that's where it's <u>all</u> at, but that's where the need is, and I hope that when all is said and done, that need is met.

POLICY

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INSTITUTIONAL RESEARCH NEEDS TO MAXIMIZE GEOGRAPHIC INFORMATION DEVELOPMENT

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ABSTRACT

Recent research and commentaries suggest that institutional factors influence information technology adoption to a greater degree than technological capabilities. Accordingly, our national research agenda regarding geographic information should focus on the goal of Multipurpose Land Information Systems, and the process of interorganizational coordination needed to meet this goal in addition to Geographic Information Systems and other tools and technologies. Some suggested research areas include topics in functional applicability; information, capital and human resources; sector development, including federal, state and local governments, academia, private sector and professional associations; definition of organizational roles and responsibilities; policies, directives, and authority; social issues; and the development of our national resources and appropriate metadata.

1. INTRODUCTION

A broad focus on "geographic information" (GI) is suggested as the environment for appropriate research and a conceptual basis and framework from which to disaggregate, integrate, access, and display information. Well over half of all public information can be references by location, including natural resources; infrastructure; land use and cover; demography; land tenure; and geographic, legal, and geodetic references. It is developed and used by virtually all public agencies and many diverse private sector interests, thus providing a linking mechanism between these entities. Technologies and tools such as Geographic Information Systems (GIS), remote sensing, and satellite surveying are improving the accuracy, management, and usefulness of GI. A broad focus can maximize GI technologies, but also general information technologies such as data base management systems; telecommunications, distributed systems, office systems, artificial intelligence, real-time systems and others.

Multipurpose Land Information Systems (MPLIS) are the most commonly viewed goal or objective of efforts in this field. Regardless of available technologies, this goal is generally considered as a way to maximize increasing information resources and investments with widespread benefits for all.

Some general trends and conditions influence the development of MPLIS. Governments are increasingly faced with multidimensional and multijurisdictional issues and decisions, often with reduced time frames and financial resources, and greater impacts and complexity. Public decision makers often do not have information available or in the proper format for their needs. They are also experiencing greater expectations for services, efficiency, accountability and fiscal responsibility. Improved effectiveness of information resources can assist in addressing these needs and public management in general.

Government has a unique role as primary creator, disseminator, user, analyzer and regulator of information. It also has a social responsibility to both protect information and provide it to the public. There is unprecedented growth in the development and use of information technology, but research reveals a 10 to 15 years gap between its development and widespread adoption.[1] When implemented, it often results in increasing fragmentation and incompatibility of information for multifunctional purposes. At the same time, single purpose legal directives and reporting requirements increase while recordation methods often grow out-of-date. Despite declining computer costs, information costs have been increasing at all levels.

These trends and conditions point to an increasing need for multipurpose and interorganizational information resources. The increasing volume of GI, entities generating and using it, and applicable technologies suggest that this is particularly true regarding GI. Thus it is suggested that a key process to achieve the goal of MPLIS and GIS implementation is interorganizational coordination. Accordingly, the research agenda must also focus on this process and the following issues in addition to technological development to achieve this common goal.

2. CURRENT INSTITUTIONAL RESEARCH

Even when considering the fast pace at which information technology is becoming commonplace in our lives and organizations, there is limited empirical research about the factors influencing its adoption in governments. There has been virtually no research conducted about the factors affecting GI technology adoption. While some general research has been conducted at all levels of government, the largest body of research about computing in public organizations has been conducted during the last 15 years by the Public Policy Research Organization (PPRO) at the University of California, Irvine, with a focus on local governments.[2] Their findings generally apply to other levels of government as well. With this symposium being held to help define the research agenda for an upcoming National Science Foundation (NSF) award for a National Center for Geographic Information and Analysis, it is additionally appropriate that these findings are considered as much of this research was also funded by NSF.

In a recently proposed theoretical framework for analyzing the factors affecting the adoption of information technology, Kraemer and King at PPRO describe "technological infrastructure" and "organizational context" as the two main categories of influences affecting these adoptions.[3] The most rapid rate of development or change is in technological capabilities, thereby creating organizational opportunities, but they suggest that organizational context is the dominant force affecting change. They conclude that, "regardless of the significance of new technological developments, ... (they) will not be incorporated into organizations unless prevailing organizational commitments permit and encourage their adoption."[4]

Recent commentaries by professionals in the GI field also suggest that more in-depth institutionally focused research is needed. Dueker concluded that the "technology ... has increased significantly, but institutional innovation has lagged", and "MPLIS objectives make a purely technological fix insufficient."[5] Chrisman asserts that GIS should be designed to meet social goals such as equity and that "technical concerns must remain secondary."[6] In addition, it is increasingly observed that technological capabilities are and can not be fully utilized without institutional reform and attention to broad social and political issues.[7 8] Further, in comparing this country with others, our less developed organizational attention to this field, and decentralized and somewhat fragmented form of government, may restrict our ability to maximize technological capabilities to help improve public sector effectiveness and compete globally.

The broad nature of GI and wide variety of factors influencing technological adoption and its usefulness

for multipurposed needs, makes a research agenda difficult to define and accomplish. The following suggestions are important factors, and potential research areas for successful implementation of MPLIS and GI technologies.

3. TECHNOLOGIES

Technological capabilities are increasing at an unprecedented rate while costs are decreasing significantly. Hard and software independence and merging capabilities are also increasing and provide additional incentives for organizational adoption. Many technological improvements are occurring in areas related to GI, specifically GIS, remote sensing, image processing, satellite surveying, and others, but also in general information technologies. The volume of information, numerous sources and networking technologies facilitate distributed rather than centralized systems. Full utilization of GIS and MPLIS requires consideration and maximization of general information technologies including telecommunications, reprographics, artificial intelligence and others. Focus and research is needed to utilize today's general information technological capabilities to, with GI technologies, improve the generation, accuracy, completeness, timeliness, storage, retrieval and manipulation of GI.

4. FUNCTIONAL APPLICABILITY

To be useful, technologies must be applied to existing needs and problems. GI technologies can be applied in four general areas or combinations thereof. Firstly, natural and cultural resources, usage and regulation are important application areas where GI technologies, such as GIS and remote sensing, have been applied. Secondly, application in physical resources or infrastructure, such as transportation networks and utilities, are increasing as maintenance of these capital intensive systems receive growing attention. Technologies such as computer aided drafting, protogrammetry, and satellite surveying have been traditionally applied in this area. A third area is socio-economic information or human resources such as health, employment, housing and voting habits of people. A fourth area is institutional and financial applications such as land use, zoning, and tenure; including property rights, valuation, regulation and ownership; public lands management; expenditure distribution; revenue generation; fiscal impact analyses; and risk evaluation and management. Traditionally, GI technologies have not been widely used in these areas, but new opportunities are being recognized and utilized.

Each of these areas has numerous single purpose applications within it, but a useful trend is consideration of related needs when developing applications. Another trend is to build integrated systems to utilize information from more than one of these GI categories. Some applications are evaluating environmental impacts on public health, public safety (police and fire), emergency preparedness and management, optimizing site considerations for economic development, and broad organization wide needs. Technologies applicable for each of these four application areas and their integration for multifunctional needs should receive research and development attention.

5. RESOURCES

Four types of resources are essential for the development and implementation of MPLIS and GI technologies. Each requires examination in a research context.

5.1 Information

Information, rather than solely technology, must be considered and developed as a key resource like personnel and capital in the emerging "information society". In general, applicable information resources are traditionally considered as digital cartographic data as input for GIS. More recent capabilities to access and display automated tabular data as attribute records, image processing and satellite positioning have expanded this scope. In addition, most GI still remains in a manual form, such as manual records, photography and maps, and thus should and are also being considered as GI resources. Systems should be designed to geographically reference these manual forms as well as other automated systems. Therefore, research attention should help design multipurpose geographic reference frameworks. Geodetic, cartographic and legal referencing are all needed. At the local level, and for state and federal land owners, the parcel is the lowest common denominator to disaggregate GI resources to facilitate accurate and maximum usage for multiple purposes. Smaller scales or larger units, such as census tracts, zip codes, and political boundaries, might be appropriate and cost effective for data handling and access for other purposes. Reference and design of GI resources should be based on individual and collective needs, when possible, as can be recommended by appropriate research.

Commonality of data can be achieved through guidelines, standards, uniform data definitions, data dictionaries, and increasing hard and software independence. National digital cartographic standards are in the process of being finalized. These standards are essential to ensure compatibility at the federal level and will hopefully lay a foundation to build compatibility for more detailed state and local data. Research attention to this area would be helpful to many local entities and help ensure the compatibility of their data for state and national uses. Finally, to be most useful, data must be secure, accurate, accessible, maintained, integratable and timely. The research agenda should include identification of mechanisms to ensure these needs are met.

5.2 Capitalization

GI development is traditionally constrained by the public or "free" nature of governmental information. An economic incentive does not generally exist in the public sector to invest in or maximize information resources, and especially not for multipurpose needs. An exception is when it has single purpose applicability and funding based on user fees, such as in utilities, which accounts in part for the emerging growth of GI development in the infrastructure area described above.

Financial analyses have been limited, and are needed to document the costs associated with GI development and use in general. In addition, costs with and without MPLIS and GIS, identification of opportunity costs and model cost/benefit analysis methodologies are needed. Applications research in financial areas would also be useful to help justify investments on economic grounds. Capitalization and financing mechanisms such as general appropriations, cash funding through user fees, development of information as a funded utility, partnerships, and privatization should be analyzed and evaluated for potential impacts on information design, development and use.

5.3 Human Development

Awareness, vision, a sense of "community" and spatial consciousness are critical factors to build a much needed critical mass to increase the rate of integrated GI development and implementation of MPLIS and GIS. This author clearly remembers the time and factors leading to this personal understanding, but relevant factors differ for people based on their unique perspective. Our country's population is characterized by strong individualism and a "frontier spirit" which has contributed to our fragmented development of a GI reference base and lack of a custodian. Cooperative efforts and information networks are frequently considered appropriate with this condition, but research attention and development is needed to include and encourage participation by different people and disciplines involved in GI.

Leadership and "project champions" are frequently considered as primary needs for the successful adoption of innovation. Cases are sometimes cited where other factors might be lacking, but implementation is successful due to a particular individual. Evaluation of personal understanding, managerial competency, and drive as a public servant, are needed to help build these strengths in others. In addition to identifying these personal qualities, it is important to select appropriate positions and actors within organizations as essential allies and partners to implement MPLIS and GIS. Research to evaluate and determine appropriate partnerships, personal networks, teams and scopes of effort would be helpful.

Multidisciplinary education is a growing and critical need for successful human development in this field. Some argue that a new discipline is needed. "Knowledge engineers" are emerging. Research is needed in appropriate curricula development to educate both regular and continuing education students about how technologies can be applied to functional areas in addition to technologically based education. It appears the availability of technically competent professionals might not meet future demands. Research is needed to project employment needs and capabilities to encourage curricula development and students to meet these demands. Students should also be educated in public policy and administration, planning, finance, intergovernmental relations, records management and land recordation to become successful implementors, users and managers.

Human development efforts and educational programs should vary by targeted group. For example, elected officials are solely responsible to the electorate and often have short terms of office. Thus it is sometimes difficult to convince them to invest in projects that might not achieve results until after their term is over. Accordingly, short term visible accomplishments should often be included in the project design to ensure political justification. Managers desire information to promote greater productivity and decision making capabilities, while users need more programmatic information. Attention to these differing needs, but also incentives for working together should be incorporated in implementation research. Technological development in user interfaces and artificial intelligence is increasingly important to maximize human potential in this field.

5.4 Systems and Facilities

A wide array of systems and facilities generally make up an organization's technological infrastructure. Some identification, suggestions and prioritizations of appropriate capital investments, particularly in systems linkages through communications networks, and data input and output devices would be a useful focus for research efforts.

6. SECTOR DEVELOPMENT

Resources, inventories, development and analyses are needed in all relevant sectors to maximize the capabilities and integration of MPLIS and GIS to use information and resources from many organizations.

6.1 Federal Government

For decades, both the executive and legislative branches have been addressing GI from various perspectives.[9] Rising costs and expenditures, with increasing threats of redundancy and incompatibility, have received more recent attention in the 1980s. In 1982 the General Accounting Office concluded that $45 million was spent on computer mapping between 1970 and 1981 and identified areas of duplication. The Congressional Research Service published a study in 1987 concerning the incompatibility of data generated by various state and federal agencies in the Yellowstone ecosystem. It recommended that a GIS framework be considered to manage these various data sets and such a project is underway. The Office of Technology Assessment is conducting a study of federal information dissemination to state and local governments and will consider the GI perspective in part of this analysis.

Federal agencies were directed by the Office of Management and Budget (OMB) in 1983 to coordinate digital cartographic activities, resulting in the Federal Interagency Coordinating Committee on Digital Cartography (FICCDC). Improved coordination, some analyses and proposed exchange standards have resulted. A Federal Geodetic Control Committee (FGCC) exists with many of the same agencies, to help establish a densified geodetic network in coordination with state and local governments. Numerous activities and pilot projects are underway, but inventories and analyses of these efforts are limited. Last year, OMB proposed that GIS be one of 17 major systems to be analyzed by their office. FICCDC and its counterpart in the Department of Interior (IDCC) have begun reviews and inventories, but further inventories of digital and other data from various sectors, and accessible in a GIS format would be an excellent resource and goal. The U.S. Geological Survey and Bureau of the Census entered into a historic agreement to build the first digital database of the country to support the 1990 Census, but much more can be done to maximize its value for other purposes. A research agenda could help develop an overall view of federal activities and needs to develop recommendations for national policies, executive action and legislative initiatives.

6.2 State Governments

States are emerging as a key sector in this field for many reasons. This is due to federal financial difficulties and delegation of responsibilities, growing state activism and self-governance to help improve their economic climates. States create legal and operating environments for local governments. They also can reference and access federal information and build linkages with local governments. However, to date, states have received less research attention and analysis regarding information technology than the federal and local governments. An initial inventory and analysis of state GI activities has been conducted by this author, and a network of state representatives is emerging, but these efforts identify the need for further research.[10] It is suggested that a research concentration on this sector could result in needed statutory models to assist both state and local governments. This focus also would provide useful comparisons of experiences and serve as building blocks and "laboratories" for much needed federal GI policy development. States are competing with each other in economic development efforts, but this is causing improvements in all. Regional partnerships are also emerging and a focus on GI development can assist these trends and other statewide issues.

6.3 Local Governments

Municipalities, counties and special districts are developing GIS and MPLIS, but like all levels of government, at a much slower rate than the growth of technological capabilities. Many advocate that MPLIS initiatives should begin at this sector or at "grassroots" levels, and the vendor community generally sees the existence of almost 80,000 units of local government as a fertile area for market development. This sector has a long and complex development time line to be organizationally able to build multipurpose and interorganizational resources and systems. It also has generally greater information, capital and human resources needs than the federal and state governments.

Counties traditionally manage the greatest amount of land information at the parcel level, but usually in departments or administrations managed by elected officials. With responsibility to the electorate, rather than a chief executive or administrative officer, they often do not have incentives or direction to modernize their systems or work with other departments or governments. Municipalities provide most services to the public such as utilities and public safety, and direct and regulate land development, but they rely on counties to manage land information bases for many needs. In addition, special districts provide services such as utilities, schools, fire and others, and exist for specific geographic areas. Regional associations of governments and non-profit utility notification centers are emerging to also develop and manage GI.

Many excellent projects are being developed throughout the country and many local government professional associations are beginning to review and present programs on various aspects of this field. However, inventories, understanding and evaluation of this sector's activities, needs and opportunities would assist these entities, help develop linkages with state and federal agencies, and incubate areas for private sector development and value added information.

Noteworthy interorganizational approaches are emerging, such as in the partnership of the City and County of San Diego; with various local governments and utilities as in Indianapolis; and public/ private partnerships as in Ada county, Idaho. Comparative case studies analyses, evaluations, and potential models should be developed in addition to general reviews of the huge local government sector.

6.4 Academic Community

Like in the other sectors, initiatives are flourishing, but the country's strongest institutions are currently competing with each other for NSF's GI and Analysis Center. As in the states, this competition has many positive aspects. It is hoped that after final decisions are made, other academic institutions can conduct research to complement the Center as additional research areas are identified by the proposals and this symposium. NSF is receiving GIS related proposals in response to other solicitations and it is hoped some conceptual and useful linkages can be made between them and the Center. To maximize available funding, perhaps research in functional applications and GI technologies can be supported by these other solicitations, allowing the Center to concentrate on more broad based, institutional research. In any case, like the other sectors, inventories and publicity about academic activities and programs would be extremely helpful in the educational process to build needed human resources.

6.5 Private Sector

Though GI technology adoption has not occurred at predicted rates, marketing efforts are expanding and new companies are emerging to stimulate such growth. The private sector should address current research findings which suggest that institutional reforms are needed to avoid fragmented and duplicating efforts by conducting and supporting relevant research. Larger companies have traditionally sponsored research in information technology adoption and should do so in the GI area as well. Avenues for companies to work together, such as private industry councils, are needed and should be stimulated by governmental or academic initiatives. Companies can generate capital and potentially create nonprofit corporations to meet some of the needed research agenda. They could help sponsor and conduct inventories and educational programs, analyze and compare case studies, and evaluate privatization options within criteria established by the public sector. They also should document the GI industry and establish business networks to maximize strengths and partnerships while reducing costs, and helping the public sector through public/ private partnerships. These efforts will also help identify and develop markets for further corporate growth.

6.6 Professional Associations

Today there are numerous associations concerned with GI issues, including public managers such as the International City Management Association (ICMA); functional users such as in public works, law enforcement, assessors and planners; and data developers such as the American Association of Geographers (AAG) and the American Congress on Surveying and Mapping (ACSM). Broad based groups supporting all of these areas for one level of government, such as the National Association of Counties (NACo) are also addressing GI issues. The educational and integrating roles of the associations will grow as well their numbers both in membership and interested organizations. Some organizations, such as the Urban and Regional Information Systems Association (URISA) and the Institute for Land Information (ILI) are serving as umbrella organizations and are working together to define and capitalize on their unique strengths to help address a broad spectrum of needs. Progress is occurring, but could be aided by a research focus to help identify roles. Currently it seems at least one GI related conference or session is being held each week by one of more of these groups and association involvement is escalating. Concentrated focus on appropriate roles, functional applications, level of expertise, memberships, audience and specific messages would help everyone select relevant groups and conferences to meet individual needs and maximize their time and budgets.

7. DEFINITIONS OF ORGANIZATIONAL ROLES AND RESPONSIBILITIES

Existing general government trends and the above sector review reveal the growing overlap of interests and development in GI. At the same time, functional redundancy, differing reference bases and financial consciousness are increasing, and the need to work together to maximize resources and develop MPLIS continues to escalate. Departments, agencies, governments, academic institutions and numerous private entities compete, but must also find common ground and work together to accomplish common goals. In particular, information resources must be designed with other purposes in mind to develop MPLIS. The cost effectiveness of multiorganizational approaches is being evidenced, such as in a 1987 Study by the Joint Nordic Project. They concluded that single agency projects result in benefit-cost ratios of 1:1, multi-agency projects with 2:1 and multiorganizational approaches with 4:1.[11] Further evidence of these benefits, and case examples of intergovernmental and public/ private/ academic partnerships should be documented and evaluated, including possible models to serve as useful examples.

Definition of appropriate roles and responsibilities of various sectors is needed for the development, maintenance, and networking of various data sets. Understanding of information needed for specific

purposes, whether it be policy development and strategic planning, operational management, or the location of a utility line, will help determine these roles and responsibilities as well as mechanisms to fund them. Frequently GI is developed for a single purpose. This is often the case today, such as in infrastructure or utility management. Even if without funding, other potential users can participate in GI resource designs. If these future users are not able to subsidize development, developers can often be convinced to maintain compatible data sets. These and other implementation strategies, as well as definitions of appropriate roles and responsibilities, should be an integral part of the national research agenda.

8. POLICIES, DIRECTIVES, AND AUTHORITY

General information policies are emerging in the public sector as the general focus moves from information technology to also include information resources. Coordination groups are emerging to address this broad focus. For example, the State of Minnesota has three advisory groups: an Information Policy Council consisting of policy advisors and deputy directors of agencies; a Systems Advisory Council with agency data processing directors composing its membership; and an Intergovernmental Information Systems Advisory Council. Their legislature recently created an Information Policy Office to also help coordinate activities between agencies and governments. These and similar initiatives are resulting in the adoption of policies assuring that information is an organization-wide, rather than solely an agency or departmental resource. By doing so, data compatibility and maximum usefulness for top decision makers can be assured, but it is an evolutionary rather than revolutionary process.

Recently we are experiencing an integration of general information policy and GI policy. This is healthy, but difficult, as GI policy requires development of information as an organization-wide resource, but also as an interorganizational resource to be most valuable. An increasingly important element in the current research focus on the adoption of information technology is the influence of external factors. This is also appropriate for GI research, but must additionally analyze the application of external influences and the process of interorganizational cooperation needed to meet the MPLIS goal.

Development of appropriate executive and legislative directives to apply policies and implement and maximize MPLIS and GI technologies are also an appropriate research focus. As noted, OMB directed federal agencies to coordinate digital activities, and some Governors and Legislatures have taken similar action to coordinate some or all aspects of GI. To date, only a few states are known to be directed to coordinate GI in an integrated manner, but many states and local governments are struggling with similar issues. Identification, analysis and evaluation of these and related directives, as well as development of models, such as legislation, are appropriate for the GI research agenda. Directives and authorities for the development of MPLIS are virtually non-existent. Of all important factors in GI development, technology is improving most rapidly, while the appropriate legal framework is probably developing most slowly. In addition to executive and legislative directives, administrative regulations and judicial review are important elements of this framework. Existing directives have often reinforced the disaggregated nature, responsibilities and development of GI in this country. Many organizational and technical risks exist in development of MPLIS, but they are compounded by lack of authority and legal questions. Potential liabilities for inaccuracy, misrepresentation and unauthorized disclosure are just a few areas of concern, often without precedence. The research agenda must include identification, analysis, and evaluation of relevant legal frameworks, and develop models to direct and maintain MPLIS and GI development.

9. SOCIAL ISSUES

Many of the above issues are related to the wide array of social issues related to information development. Information must be designed and managed to abide by requirements for access, disclosure and confidentially. A variety of directives exist and are being revised to address this increasingly complex area, especially in regard to GI where data exchange occurs frequently. MPLIS should be designed to ensure equity, but such an objective is increasingly difficult as emerging public/ private partnerships might confuse the design of resources for strictly public good. The research focus should address the needs of the public, including both individuals and the common good, as well as social issues, as primary aspects of MPLIS and GI resource development.

10. NATIONAL RESOURCE DEVELOPMENT

This country has traditionally had more information about itself and technology adoption than any other, but we can not maximize its usefulness without appropriate organizational focus, modernization, and coordination. While governments are in competition for increasingly scarce resources, their roles are becoming less distinct and their functions and information resources are overlapping. The public is increasingly frustrated by growing levels of bureaucracy and tax burden. We are constantly reminded of technological developments, and other incentives and demands for cooperation, reduced redundancy and improved effectiveness, but a focus and support system to facilitate improvements is essential. An investment in our shared future can be made by developing and marketing our information resources to maintain our strength as the world's knowledge and technology center. Proactive development of GI creates a focus, opportunity, and process for working together. It also can help maximize our resources, technological capabilities and other investments; improve public management and effectiveness; incubate business development; create and expand markets; and strengthen our international competitiveness. Analyses and comparisons of approaches in other countries, many with more developed MPLIS and GI policies, would also be a useful component of our national research agenda. A research challenge is to develop our GI resources, applications, technological capability, and institutional framework from a strategic perspective to improve our competitiveness while effectively participating in the global community.

11. METADATA

To effectively steer the future and support MPLIS and GI resource development, we must understand where we are, what we have, where we have been, what works and does not, and why. Needs for MPLIS and inter-organizational coordination have existed through time, but technology has only recently emerged to encourage and support these initiatives. A historical review and analysis from both perspectives would be a very useful addition to the research agenda.

A common vocabulary and definitions are sorely needed. Baseline information about initiatives, technological capabilities, resources, applications, pilot projects, directives and other activities is needed for all sectors. This "metadata" development will help identify our current status, locate and reduce redundancy, encourage commonality and sharing, and establish resources for future work. It also will improve understanding of successful approaches, and identify potential pitfalls, barriers, needs, partnerships, funding mechanisms, opportunities and cooperative approaches. Case studies should also be conducted to avoid repetition of failed approaches and identify successful models for replication. Additional research needs and opportunities will also emerge through this process.

12. CONCLUSIONS

Available research about the adoption of information technology in public organizations and commentaries by professionals in the GI field are reaching similar conclusions. They suggest that increasing attention is needed regarding institutional issues as the primary factors influencing technology adoption. It is suggested that instead of considering GIS as the goal and primary research focus, GI should be considered as the research environment and GIS and other technological capabilities evaluated as tools. Therefore, MPLIS should be considered as the goal and interorganizational coordination as the non-technical process to achieve this goal. From this frame, a variety of suggested institutional research areas are proposed to complement and maximize the value of technological research.

The suggestions outlined in this paper are made with the realization that all of the wide array of research needs suggested here and elsewhere can not be funded by NSF or accomplished by the new GI and Analysis Center. These institutional research needs are suggested to identify additional areas requiring analysis and development in addition to technological research to meet our broad, long term goal of MPLIS and GI resource development. Initially, a broad national focus and research frame is needed. Once conceptualized, the realistic role and expected accomplishments of the Center can be determined. Ideas and direction can then also be provided, and financial support gathered, for research work to be conducted by other academic institutions as well as the public, private and other sectors. It is hoped the institutional research ideas presented here can also help serve as background and focus for needed strategic national policies regarding geographic information resources and technologies development and application.

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LITIGATION OVER INFORMATION: THE USE & MISUSE OF MAPS

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Introduction

Land and geographic data and information are managed to provide appropriate support for those who make land-related decisions.[1] Maps, in paper or digital form, are common representations of these data and information. They appear in the negotiation and debate over the impact of land management decisions. Thus, an aspect of information management is the impact of litigation on the quality, timeliness, and other attributes of the spatial data and information that support these decisions.

Information Concepts

The buying and selling of information, including maps, raises the question of the extent to which information is similar or dissimilar from other traded commodities.[2] One distinguishing feature is that it is difficult to measure the quantity of information actually acquired. One can buy specific types of information, such as health information from a doctor or information contained in a book on a particular subject. However, measuring the amount of information acquired in a process is a problem which distinguishes information from other products.

Another feature which distinguishes information from other commodities concerns the ability to assign property rights.[3] A precondition for operation of a market is that property rights are created and can be protected. In the absence or limitation of such rights, suppliers would either find it unprofitable to produce the product or, if produced, tend to underproduce it. If the producer cannot prevent use of the product in the absence of payment, then the ability of market processes to generate the optimum amount of the product is compromised. For information products, there are varying degrees of appropriability. For example, the patent system seeks to assign property rights to knowledge in order to create incentives for its production. The limited ability to maintain property rights in information products is a distinguishing feature and raises the question as to the extent which market processes are workable for these products.

Another distinguishing feature of information is that it is sometimes a public good. In economics, a public good means that use of the product by one person does not curtail use by another. In the contrasting case of a private good such as a car, use by one person denies its use at the same time by someone else. Maps are a common public good produced by governments at all levels.

Maps in the Land Management Process

The ultimate uses of maps and geographic information are citizens, planners, public officials, lawyers, judges, bankers, and similar decisionmakers, often without expert knowledge or experience with the spatial products or the scientific measurements they represent.[4] These users seek data and information, at reasonable cost, as input to a process that (a) reduces the uncertainty of their planning, investment, and development decisions and (b) provides opportunities based upon the new knowledge obtained from these data and information.

Maps contribute to the establishment of land management policy. Policy formation typically relies upon maps at small scale, those with at scales of 1:10,000 or less. However, policy implementation requires spatial data representation at larger scales, those with resolution at the parcel level where specific rights and interests are affected.

Controversy over land management and use appears in the courts, administrative agencies, and private negotiations, or wherever decisions about land use are made. Maps are one contributor to the resolution of these conflicts. They are a form of scientific evidence, representing the results of land measurements and observation made in conformance to scientific methods.

Maps can contain errors, be poorly designed, and used inappropriately and in ways unintended by their designers.

One who feels unfairly harmed by a land management decision can appeal to the courts. The legal process provides a context where maps are used as scientific evidence. Litigation indicates a not unexpected demand by the courts for adherence to the objectives of statutes, laws, and rules. The quality of the spatial products used is, in part, a measure of that adherence. Applicant, agency official, and citizen each have an individual perspective on the data and information. The integrity of these individual perspectives is important. An adversarial relationship can exist wherever data is a matter of dispute. The idea that a neutral agency will create a non-contentious data set for decisionmaking is inconsistent with our adversarial legal system and is not good policy in a society where we respect the right of the individual to question the facts that are used to determine rights and interest.[5]

Mapmakers and users are concerned about the liability that can arise from reliance upon information later shown to be inappropriate for the particular land management decision. This liability is determined in cases where a person alleges harm from a poorly made decision, and the controversy brings scrutiny of the supportive information. An examination of these cases is a study of the use of scientific evidence in conflict resolution.

Liability Theories

Legal theories of the liability for errors and misuse of information are of three types. These are contract, negligence, and strict product liability.

Contract liability arises where the terms of an agreement between producer and user allocate responsibilities. The issue is important for those who make contracts for the production of maps. The agreement sets standards for products and services provided under the arrangement. Contract provisions are upheld by courts where the product or service is clearly described. Where a computer and/or its product is involved, the seller should carefully describe standards that apply to the computer program and/or computer product utilizing warranties and warranty limitation. The buyer should obtain a warranty that the provided product and/or service is suitable for the buyer's intended purpose, a purpose clearly described in the contract. Written contractual arrangements between map-producing public agencies and a consuming public are rare.

Negligence arises where a person fails to exercise the standard of reasonable care normally expected of someone in the same situation and a harm to another results. Courts and legislatures have defined the standard of reasonable care for many everyday situations. Map producers and those who use maps for land-related decisions are often covered by this type of standard.

Computer-based information present additional complications. Complaints, for example, allege that inaccurate computer information has led to improper repossessions, utility service terminations, loan defaults, etc. The so-called "computer-error" is often found to be a failure of the system owners or operators to respond reasonably to mistakes brought to their attention. In these circumstances, it seems likely that the basic principles of reasonable care will apply.

For automated systems, failure to select and maintain the hardware and software that executes the required tasks may constitute negligence. Also, data entry systems must be designed to achieve an acceptable level of errors. Finally, the marketing of products and services may require marketing plans that adequately conveys to foreseeable users an understanding of what the product and/or service can or cannot provide.

Strict product liability, unlike negligence does not require that the injured party present evidence that the producer acted improperly. Instead, the injured party is required to show that the product itself is of an inherently dangerous nature for the actual use and that this, in fact, caused the harm.

Undoubtedly, uses unanticipated by map designers will arise. These may be the most dangerous in terms of potential liability, particularly if original designers are no longer available.

Liability Scenarios: The Case of Maps

Information services and products cannot be operated without some errors in the data, the information product, or in the software for the case of automated systems. The appropriate level of care in the design, selection, and operation of systems is difficult to establish because of the attributes of information.

Maps may contain errors, be poorly designed, and used inappropriately and in ways unintended by their designers. These problems are categorized as follows:

1. Errors and omissions in represented locations.
2. Error-free representations that, nonetheless, create foreseeable confusion.
3. Use of spatial products for unintended purposes or in unintended ways.

Errors in represented location, and in the information about those locations, typically result from measurement and data handling mistakes. National map accuracy standards prescribe a reasonable level of misrepresented locations.[6] In automated mapmaking, data entry occurs when measurement data are transformed into numbers and stored in a computer file or when the information in existing maps is digitized. A court is likely to consider the process used for data entry and whether or not a reasonable standard of care is established and utilized in the process design and implementation, including data priority rules and training procedures, aimed at minimizing errors.

In the case of Indian Towing Co. v. United States[7] the federal government was held to have negligently failed to maintain a lighthouse whose presence was marked on charts and whose character was described in the official Light List. In Reminga v. United States[8] the federal government was held to have inaccurately and negligently depicted the location of a broadcasting tower on an aeronautical chart, contributing to the mistakes and fatalities in an airplane accident.

Representations of error-free data can cause problems. The form of data representation can result in an information product that is confusing or inappropriate for the user's purposes.

An example of an error in the form of representation occurred in Aetna Casualty and Surety Company v. Jeppeson and Company.[9] Here it was asserted that a fatal plane crash resulted from a defective aeronautical chart

published by Jeppeson and Company a chart that depicted the instrument approach procedure to an airport promulgated by the Federal Aviation Administration (FAA) and described by the FAA in tabular form. The parties did not dispute the accuracy of data represented by the Jeppeson chart. The chart graphically displayed two views of the approach, one from above and another as a profile or side view. The court found that the chart had a defect not in the accuracy of portrayed information, but in the particulars of the graphic form of the representation. The problem was that the profile or side view appeared to be represented at the same scale as that for the top view whereas there was a factor of five between the two. The court found that the crew were misled, to some degree, by the representation and this contributed to the fatal crash.

Unintended and inappropriate uses of maps occur among public and private users. These misuses are pronounced where map designers and developers are no longer available to the user and the user lacks expertise or access to expertise about the map and its represented measurements. Inappropriate combinations of maps and spatial features often occurs.

In Zinn v. State[10] evidence of the location of the ordinary high water mark (OHWM) for a navigable lake was presented in a regulatory hearing. At the end of the process the hearing examiner sought to indicate that evidence of the lake level corresponded to an elevation of 980 feet above sea level, while the OHWM corresponded to elevation 990. This evidence was represented in the examiner's final report by marks and highlights on the contour lines of a U.S. Geological Survey (USGS) Quadrangle for the area.

Several months after the issuance of the report, the owner of the land abutting the lake, a person not a party to the earlier process, brought an action against the state. Land below the OHWM belongs to the state. The owner asserted harm from a temporary taking of her land, temporary in that the agency subsequently rescinded and withdrew its report. She asserted that the state had claimed most of her property, created a cloud on the title to her land, and deprived her of her riparian rights to the lake. The state Supreme Court found that it was reasonable for plaintiff, title attorney, and citizen to conclude, based upon a consideration of the map in the examiner's report, that the state asserted title to land depicted in the examiner's report as below the OHWM. The state was liable for the harm imposed on the landowner.

The hearing examiner had placed evidence of the OHWM, evidence in the form of observations and measurements by botanists and surveyors, into the context of the USGS Quadrangle. This data was transformed into information with characteristics of both the Quadrangle base map and the data itself. The final spatial product presents a more complex picture of the land than the observations and the Quadrangle separately.

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There was justified reliance upon a mapmaking activity that was not executed with the proper duty of care. The duty was to make an adequate statement of the location of the OHWM.

The map reader "sees" a combination of the highlighted contour, the topography and other features of the Quadrangle, and personal experience with the site. The knowledge imparted by this combination is not the same as a combination of the field observations with site experience.

An alternative presentation of the data is the statement that the OHWM is at elevation 990. This is not the same as a highlighted contour on a USGS Quadrangle. The statement does not place the data into a context established by the Quadrangle. The statement requires that the relation between the elevation and other ground features, especially property boundaries, be determined by other means than inspection of the hearing examiner's map. The words are not the same as a picture.

Another alternative is the use of a highlighted contour on a base map at larger scale than that of the Quadrangle (1:24,000). This combination could present a more reasonable representation of the relation between a particular elevation and the understood location of parcel boundary lines.

This case illustrates both the use of a base map for a purpose unintended by the professional cartographer and an inappropriate combination of a map and spatial data. Its use by a cartographic non-expert falls into the use class often described by the phrase "we used it because it was the best available map."

Speculation for the Automated Mapmaking Age

Maps & spatial data files are often combined in the process that results in a land management decision. The ability to make these combinations with greater ease & efficiency and the ability to make difficult data queries will likely increase with automation. There is a negative side-effect. While automation promotes use of maps & digital data files, it also increases the rate of map misuse, especially where operation of the system is in the hands of inexperienced clerks far removed from system designers and developers.

There are two limiting solutions to the problem of map compatibility. These rely upon the establishment of compatibility by a priori and ad hoc means. The two approaches can be used in combination.

A priori methods build map compatibility into the feature location data as they are collected. The map data have attributes that are always available

to those who combine maps and spatial data. These attributes are created when the feature location measurements are tied with known accuracy to a common geometric reference framework, a set of identified and marked points on the earth's surface whose relative positions have been accurately observed and described. This framework, commonly called a geodetic network, permits the common spatial referencing of all land features.[11] It provides the basis for a uniform, effective language for interpreting, combining, and disseminating land-related information. With common features measured and described relative to the same framework, map combinations can be made reliably, and with a measurable degree of accuracy.

Alternatively, spatial data maps, and data files are obtained and combined by ad hoc processes that strive for a pleasing aspect, sometimes without regard for the accuracy of the represented features. These occur when two or more maps are combined, manually or automatically, without the aid of common, accurately-located positions. These processes, known traditionally as rubber-sheeting for manual mapmaking and describable as creative programming for automated techniques, can result in a map inappropriate for a particular decision when generated or used by persons without cartographic experience and knowledge.

Digitized maps and data files are combined by means of sophisticated computer programs, with rules for the priority of data elements. These systems are designed by their developers to discourage the intervention of clerical users without cartographic expertise. In the hands of such users, and with reliance upon facile manipulation of spatial data without sufficient concern for inherent data quality and its compatibility, the possibility remains that ad hoc combinations by automated means will increase the inappropriate use of maps.

A challenge to designers and builders of systems that produce maps is how to balance reliance on ad hoc measures, with their potential for individual and specific input, with the efficiencies of a priori methods.

Summary

The traditional mapmaking problems of errors in feature location, form, and inappropriate use remain in the age of automation. In addition, automated mapmaking is so facile that special attention must be directed to the problems of map combination and compatibility as common use of computerized systems moves from the designers to the cartographically inexpert users.

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Geographic Information Systems: Issues Arising from the Proliferation of Information

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Abstract

Geographic information is proliferating at an unprecedented rate due to the impact of electronic data processing. Three basic issues must be addressed in order to ensure effective information management: accuracy, access, and applicability. Accuracy, or the reduction of uncertainty, includes the following processes: data capture, processing, and compatibility. Each of these levels can introduce error and skew results. The issue of data accessibility balances the public's right to know with the individual's right to privacy. Public agencies are obligated to release raw data but not processed information on request. Integrated databases compiled by public agencies can be viewed as resources that can be marketed to the commercial sector. Applicability of information leads to effective decision-making, the satisfaction of end-users, and, for public agencies, equitable access. Systems generated and motivated at the application (end-user) level are generally more productive initially than large-scale corporate systems. Consensus among users on data compatibility and goals in the initial stages of implementation will increase longterm effectiveness.

1. Introduction

With the advent of electronic data processing, it is now possible to generate an overwhelming amount of output with very little effort and even less thought. As a result, modern society is virtually drowning in a sea of information. Data that has been effectively captured, stored, processed, analyzed, and presented in a timely and comprehensible way to the intended party are an asset. Data that don't meet these standards are less than useless as they tend to obscure relevant information. Specific issues arise as more private and public agencies amass large databases. Most of the research in the field of geographic information and analysis has been focused on the technical aspects of developing and operating spatial information systems. Little has been written on the management of the information generated. However, as more systems come on-line and mature, the issues arising from the proliferation of information will gradually make their way to the forefront of social science research. This paper will identify and discuss three major areas which need to be fully explored: accuracy, access and privacy, and the longterm effectiveness of a system. By looking at each area closely we will outline some guidelines for the management of the ever increasing flood of information.

2. Accuracy

Data is available everywhere. But in their raw form they are nothing more than than numbers. Data must be processed in order for them to be of any use. However, three factors affect the usefulness of the processed data: how was the data captured, what kind of processing has been done, and how applicable is the processed data to the original purpose of the data. The goal for any system is to reduce uncertainty to such a level where decision-making becomes more effective (Wisconsin Land Records Committee, 1986).

2.1 Data Capture

Data capture and entry is one of the first steps in implementing a GIS. But as data are entered into a system, three areas of uncertainty are encountered: locational, classification, and value (Smith and Honeycutt, 1987). Locational uncertainty is directly related to place and scale is the deciding factor. As scales change, relative locations also change. For instance, a digital 1:100,000 scale quadrangle is a sufficiently accurate basemap for the new Census Bureau Topologically Integrated Geographic Encoded and Referencing (TIGER) files as the smallest nonvisible spatial entity is the block (Behrens, 1984). However, using this base map to install water mains and fire hydrants to serve these blocks would be doomed to failure. Accuracy is a function of scale which is ultimately a function of cost (McLaurin, 1987).

The problem of what scale to adopt for gathering data is a barrier to the concept of shared databases. It is not uncommon for a multitude of agencies, private, public, and quasi-public, to each build a digital base map for the exact same parcel of land but at slightly different resolutions. Substantial savings could be realized if the agencies could pool their resources for a common base. However, utilities need one scale, tax assessors another, and engineers still another. A scale of one inch to 50 feet (1:600) with a vertical contour interval of one to two feet is desirable for most public planning and engineering purposes (Bauer, 1984). For agencies not requiring such accuracy, share of cost for developing such a base could be pro-rated accordingly. GIS planners should be aware of such opportunities and incorporate shared databases whenever possible. New technology is making accurate base maps more accessible to smaller organizations. The Global Positioning Satellite (GPS), when fully operational, will substantially improve the accuracy of the geodetic controls needed for the development of integrated multi-purpose cadastral systems.

Uncertainty in attribute classification is another consideration for data capture. For instance, parcel ownership is unified in a spatial context but soils or vegetation for the same parcel are rarely homogeneous. In these cases classification then becomes an issue. In the example of vegetation, many sources of uncertainty can occur. Boundaries for physical attributes, as opposed to political attributes, can be subjective assumptions on the part of the field observer. Where does one predominate species stop and another begin? Continuity in decisions is the key concept

here. Data gathering techniques and guidelines need to be explicitly laid out before field work is performed in order to ensure the highest possible certainty in data. Five different observers using five different criteria to decide where an oak forest stops and savannah begins will each place a boundary in a different location which will in turn play havoc with any assumption made using the database. Unambiguous survey guidelines will help reduce uncertainty.

The information content of attribute classification is inversely proportional to the level of generalization. As attribute categories increase in generality (ie. grasses versus forests as opposed to oak versus ash), the less amount of uncertainty there is but the information content is reduced. But as a scale is increased (ie. higher resolution) there is less uncertainty in regards to locational accuracy and information content. However, general data are of less economic value than specific data. So it is a trade-off based on economics. The accuracy required should be examined very carefully before implementing a GIS database. It is much easier to decrease the resolution of a data set than to increase it after the fact.

Value uncertainty is based on absolute spatial relationships. For instance, on a map a road is next to a railroad which is next to a stream and each is represented by a line of equal width. Yet the road is 25 feet wide, the railroad is 5 feet wide, and the stream is 40 feet wide. Although their relative location is correct, their absolute spatial value is uncertain due to cartographic constraints. Again resolution is the critical factor: the higher the resolution, the more accurate the location (both relative and absolute) and value will be. Again, economics is the key factor.

2.2 Data Processing

The second major area where uncertainty can occur is in data processing. In a case where a GIS is nothing more than an electronic file cabinet storing and displaying data, processing is not an important factor. But when analytical processes and modeling are preformed, uncertainties can be entered into the system and propagated. The most basic analytical processing such as changes in scale and projection, filtering, resampling, and other image enhancement techniques can introduce errors if not fully understood. Each time a subsequent process is performed, the error is multiplied, eventually producing totally spurious results. Processing produces new data which is no longer empirical but an artifact of the original data. The greatest value of a GIS, the ability to process and transform data to information, is also the biggest danger. Take, for example, simple scale changes. Data entered from a standard USGS 1:24,000 topographic sheet is fine for general site location. But by enlarging it using a zoom function (not unlike projecting a slide from further away to increase the size of the image, but not the information content) someone not familiar with the function might assume that a 1:6000 scale could be produced with the associated increased accuracy. This is not an uncommon mistake made by GIS technicians. When the new image is used for engineering purposes by a utility, a pipeline could be placed in the wrong parcel. What is required, then, is comprehensive documentation, not only of the database, but also of the analytical functions performed on the database. Without such

documentation, the level of uncertainty will be so high that decisions based on the resulting information might be suspect.

But documentation is not enough. Training is required in not only the basic operation of systems but in the theory driving the processing. The above example might seem ludicrous to a learned audience, but a technician untrained in statistics or cartography might still wonder why a zoom function doesn't provide more information. Again, financial considerations must be taken into account. To train an inexperienced operator (and the available pool of experienced GIS technicians is small indeed) in the 600 odd functions of a turn-key GIS might take six to nine months for just the basics of which button to push when. Not many agencies can afford to invest in supplemental training in statistics and digital cartography. In addition, once operators are trained, there are no guarantees that they will stay with the job. The turnover rate is quite high as positions always exist for trained people. Sophistication in both the theoretical and applied aspects is required to operate a system effectively.

2.3 Data Compatibility

The final factor affecting the accuracy of a GIS is the compatibility of the application to the original data. In case after case (Antenucci, 1979; Tomlinson, 1982), additional applications are found for existing databases. But are these databases suited to these particular applications? Data entered into a system should ideally be gathered with a GIS in mind. However this is often an impractical constraint. Secondary data is often of suspect quality. Problems with coverage, content, and age can be present but undocumented. Data entered into a system is usually assumed to be 'correct' by the user, but this is not necessarily the case. Data that has not been documented in respect to date, sampling technique and method, and definition of variables should be avoided. One inaccurate data layer can flaw the entire operation.

Different agencies have different tolerances for uncertainty. For example, data collected by wildlife managers for habitat studies can be approximate for inventory purposes. But when this same data is used as a basis for the permitting of commercial development, a rough field estimate could be the deciding factor on where to place a parking lot or access road, a potential multi-million dollar decision. This could be another stumbling block for shared databases. If many separate agencies all contribute to a single integrated database and agency X does sloppy work, everyone suffers. Quality control/quality analysis (QC/QA) is an important factor in the effectiveness of any GIS operation. Accuracy then, can be distilled down to two basic areas: resolution and documentation. The higher the resolution and degree of documentation, the less uncertainty associated with the resultant information.

3. Access and Privacy

The dilemma of the public's right to know versus the individual's right to privacy is an issue that will receive increasing scrutiny as individual databases become part of an integrated whole. The relationship between data and information is the basis for any investigation of access and privacy. Data that is publicly held should, with the exception of proprietary records such as geophysical exploration records that must be filed for mineral claims and the like, be available to the general public. However, once that data is processed and analyzed, the public's right to access is diminished. Other factors enter into the question of access such as cost, staff time to handle information requests, data formats, and the re-use of data (Roitman, 1986).

A public agency such as a planning department can build a sizable database consisting of tax assessment data, cable TV hookups, zoning designations, noise levels, water use and so on. Other agencies with their own data layers, such as police departments with crime type and frequency maps, health agencies with violation maps, or school districts with bus route maps, could integrate their data and process the information. The applications for such a comprehensive database for private enterprises are substantial. Real estate firms, pollsters, direct marketing companies, political groups among others could utilize these databases for targeting select market segments. However, few public agencies are in the business of data dissemination. They are service oriented and have acquired this data to support their mandated public duties, not as a marketable asset. An agency with such an integrated database might not have the extra staff to make this data available. Indeed, agencies are under no obligation to to re-format, tabulate, or process the data for the public. Freedom of information laws generally apply to original data only.

Two major groups are affected by the issue of data access: Public agencies that control the databases but are not in a position to process or market them due to economic and political constraints and private entities which would like to utilize the data. There are two approaches they could take. First, the private companies could request the individual raw data layers from each agency and format, process, and tabulate the resultant information themselves. This would effectively limit access to individuals and companies that have the economic or technical resources to undertake such a project. The other approach would be for the public agency involved to set up a semi-private entity to archive, format, process, tabulate, and market the databases. The entity could be non-profit or for-profit and services could range from simply gathering and re-formatting data to developing analytical software to improve the information content.

An advantage of the second approach is that the integrity of the databases could be preserved, an important consideration if the available data is generated from many different sources. Privacy could be guaranteed by having restricted databases reside in the generating agency. One chartered entity controlling the access and distribution of data would ensure compatible formats, consistent documenta-

tion, similar scales and cartographic conventions, and the avoidance of unnecessary duplication. It would also ensure equal access to a diverse set of users. Equity is a key concept in access issues.

Of course this is a long term solution that requires political sponsorship, start-up funding, and the support of the private sector. However, cooperation between the private and public sectors on the local level is increasing. If public databases and the information that results from data processing are readily available to all segments of society at a reasonable cost, the issue of access will not be a controversial subject. If the data is carefully gathered and and private information shielded, the 'big brother' concerns of some social critics can be avoided. However, there are no guarantees that this will be the case.

4. Effectiveness of a GIS System

A fundamental question of all systems is how can an agency measure the effectiveness of an integrated geographic information processing system? Effectiveness can be taken at two levels. In one respect, it can be an improvement of end-user and over-all organizational productivity due to system application (Nunamaker & Konsynski, 1986). By taking a larger view, effectiveness can be viewed as the balance between equality, the doctrine of equal rights, and equity, the concept of fairness (Chrisman, 1987). The narrower definition is based on internal productivity at the agency level while the latter deals with the impact of the system on the public at large.

Measuring an increase on internal productivity, necessary for the first definition of effectiveness, is an ongoing process starting at the earliest stages of conceptual planning. Initial productivity measures range from profits and operating expenditures to customers served to maps produced and so on (Schmidt, 1979). Production goals must be decided upon before undertaking an implementation project. By comparing the impact of a GIS to the stated goal of the GIS relative effectiveness can be ascertained.

This traditional approach of effectiveness is being altered by changing technology. Distributed processing is becoming an attractive alternative to centralized data management. Networking capabilities are being upgraded and stand-alone workstations are becoming increasingly inexpensive. In addition, users are becoming more computer literate. The days of resistance to computerization in a department are almost gone. Every planning department now has people who feel more comfortable behind a CRT screen than a drafting table. End users do not have to be taken by the hand and interviewed by outside consultants who will design the system. Some users are sophisticated enough to implement small, micro-based systems to run while their agency grapples with the 'corporate database' question.

Application database systems, user-driven systems designed for one or two direct applications, as opposed to corporate databases, top-down systems designed to satisfy all users in all applications, are becoming more popular for a variety of reasons (Montgomery, 1987). First, with proper planning, they can be much quicker to bring on-line. The largest expense and time consumer in any implementation project is data conversion. In the case of applications databases, however, the conversion is done at the very lowest level by the people who will actually be applying the data to their jobs. Planning in respect to format, accuracy standards, scales, symbology, accessibility, etc. must be performed before any conversion takes place. Documentation must be a requirement for every data file on a distributed system. Otherwise there is no way to guage uncertainty.

Since only a few applications are automated at the end-user level at a time, conversion of only the pertinent data needs to be undertaken. Coordination on the part of the data processing manager will ensure proper networking between end-users as well as protect against duplication of effort. A standard base-map would helps assure continuity in data. Since only application data is converted, the process can procede quickly and the output generated can be utilized in a short period of time.

An application database can be integrated into a network of other application databases to build the overall corporate or core database. Each component will be documented, compatibly formatted, and most importantly, be already on-line supporting decision-making. The general trend with large automated systems has been to implement them top down rather than from the bottom up and trust that the applications will lend themselves to the data. The application method seems to be a more efficient process for GIS implementation.

This bottom-up approach will change the dynamics of the data processing (DP) environment. Decentralization of the database will redefine the roles of the end-users and DP specialists (Noble, 1986). The DP staff, whether in-house or external, has traditionally taken the lead in every aspect of system design and implementation. However, with a more distributed approach driven by end-user applications, the DP staff will find itself in more of a support role rather than a leadership role. Functions such as hardware and software recommendations, networking, formatting, and documentation procedure will become the major duties of the DP staff. The DP staff could also tailor the newly developed core database for commercial applications and market the information.

The DP manager, on the other hand, will move further from the technical aspects of data processing and begin to manage information at the executive level. Chief Information Officer (CIO) is a position requiring not only expertise in the system itself but also in system applications and the flow of data between the various components. The CIO can also monitor productivity on the agency level and keep track of documentation. 'Quality information', by which is meant documentation on the origin of the database, accuracy standards, the path of the information flow,

is essential to measure uncertainty (Chrisman, 1983). The CIO will be the ultimate judge of data applicability. Two levels of information are produced by a system, an application level designed to help end-users do their jobs more efficiently and a management level where the information supports effective decision-making (Karlstrom, 1986).

On the first level, application, productivity measurements are easy to chart. By looking at previous productivity (ie. maps produced, customers served, etc) and comparing it to system-aided productivity (for a fully implemented system), impact can be measured and compared to cost. The applications approach is keyed to this level and this type of information is best generated in a 'bottom-up' system.

The second level, decision-making, encompasses the equity aspect of effectiveness. For private enterprise with no obligation to disseminate corporate databases to the public except in a few cases, decision-making can be judged on effectiveness within the organization. In a sense, decision support is a product. Increased profits, long-term growth, or stability result from good decision-making policies. Again, the applications approach is appropriate for implementation.

Public agencies and their databases, on the other hand, are required by statute to be accessible to the general public. The data used internally by each department to support agency productivity (applications level) must be made available upon request. If each application database is compatible in respect to format, scale, and documentation, each can be integrated into a core database for decision support and improved data dissemination. The CIO can directly access the core database for decision support analyses for long-range planning and policy issues. For public agencies, profits and growth cannot be utilized as measures of effectiveness. Equal access to decision support systems, or equity, is a key to public agency effectiveness. The more accessible decision support information is to the public, and by accessibility we could include costs for processing, availability of input/output services, directories, and analytical information, the more equitable it's distribution will be. Effectiveness in a private company can be measured as a function of the positive impact the system has on achieving company goals. Effectiveness for a public agency is judged on an equitable distribution of information resources and an improved performance in regard to it's public mandate.

5. Conclusion

Simply an increase in the amount of data will not reduce uncertainty and improve the effectiveness of an organization. Only information, data that has been appropriately processed, can make a positive impact. The databases must be documented in respect to the temporal timeframe, resolution, capture, and processing. This 'quality information' must be carried throughout the system. Only then can the inherent inaccuracies in the data be taken into account. Tracking accuracy, or at least an accurate estimation of error, is a key element in managing the flow of

data to information.

For information to be of any value it must be accessible to the appropriate people in a timely fasion. In the case of public agencies this includes availability to the general population. Integrated public agency databases can be seen as a huge untapped resource that can benefit society. Agencies that can adapt and begin a market-oriented data dissemination program will find considerable success.

Finally, any product must have the perception of value or it won't sell. Information is a product like any other. If people, either in-house or external, have no faith in the accuracy, applicability, or availability of the information, it will be wasted. In order for a system to be effective, it must be utilized. Selling a system and it's information is an ongoing process for managers (Bomberger, 1986).

These are some of the issues that will confront information managers as more agencies come on-line. The real key to information management is a thorough background on the issues involved, both theoretical and applied. The concepts involved are perhaps a bit abstract in relation to most current research, but as technical obstacles are overcome, the management aspect of geographic information will develop into an important field of investigation.

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URBAN GEOGRAPHIC INFORMATION SYSTEMS: TECHNOLOGY WITHOUT SOLUTIONS

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ABSTRACT

The industry is not providing what local governments need most from geographic information systems---answers to their problems. The term "geographic information system" (GIS) is poorly defined and misused both inside and outside the industry. It is time for research to define the some parameters and contents of urban geographic information systems. This paper discusses the areas where research of GIS applications can help move the technology forward.

1. INTRODUCTION

"I know that is what I asked for, but it is not what I wanted," could well be the motto of local government geographic information systems (GIS). People are selling hundreds of millions of dollars worth of hardware, software, and services which do not resolve the problems which prompt local government to develop a GIS. Local governments are buying the technology but not finding the solutions.

One reason for the acquisition of technology rather than the resolution of problems is that local governments are looking for a fast, easy, and complete solution to long standing, complex problems. It does not, and will never exist. Local government must take time to plan and evaluate their problems before they buy technology. However, "blaming" the client is the easy answer, and begs the question.

A second reason for technology without solutions is that "geographic information system" is a term which is poorly defined and misunderstood industry-wide. Our industry---academic, government, and the private sector---fosters misperceptions and creates false expectations in the user community by using the term geographic information system without qualifiers which specify the type of geography, information, or system. The prevailing attitude of the vendor and consultant appears to be one of *caveat emptor*. I agree that in this new technology there are no guarantees, but since that is so, is incumbent on the industry to provide an understanding of the alternatives and their concomitant risks.

We need research which provides a framework for the urban GIS. We need research which goes beyond the theory, beyond the Procedures and Standards for a Multipurpose Cadastre[1] to the problems faced by local jurisdictions. We need to understand the complexity of those problems so that the user community can

realistically judge the value and adequacy of the technologies in the light of their situation.

There are innumerable ways a GIS can be designed and implemented. When people choose one, they must be able to see the alternatives they have and the trade-offs they are making. They must be able to evaluate recommendations and the value of the products as solutions to the problems in their own particular jurisdiction.

This paper attempts to identify major areas of urban GIS implementation which require research, if the technology is ever going to provide the solutions people need.

2. THE URBAN GEOGRAPHIC INFORMATION SYSTEM

A geographic information system can be simple or incredibly complex. The basic requirement is that it must be a system which manipulates geographic data. The problem automating geographic information systems is not what can be included, but rather what should be excluded from a particular system so that the system is feasible, affordable, and most of all, effective in solving the problems at hand. The appropriate tech-nology is that which best solves the problem within the limitations set by the organization, such as time, money, and people. However, before the organization makes its decisions it must know what the alternatives are.

The urban GIS is data and the systems which create, maintain and analyze it. The data are information about the land which comprises the jurisdiction, and the people and improvements related to that land. The systems, automated or not, which manage that information are every operation and activity in local government from executive decision making to the drafting of maps. The decisions facing the user concern the amount of automation and the level of integration among those systems. Does one automate everything and integrate all activities over several years, or do you automate smaller pieces which stand alone and solve specific immediate problems? Can you do the latter without eliminating the possibility or probability of the larger comprehensive system?

Before these questions can be answered and before a local government pursues GIS technology, it must be able to articulate the immediate problems which the technology is supposed to resolve, and the long term issues which are affected by the choices of technology. The type and size of GIS selected by a local jurisdiction should depend on the problem or problems for which a solution is needed.

3. THE BASIC COMPONENTS

The urban GIS should be organized around data which are basic inventories of the entities for which the organization is responsible. Local urban government

responsibilities are defined by one very basic thing---land. The authority of local government begins and ends at land boundaries. The first inventory required for a GIS is one of the land. All other responsibilities are related to the land. These are:

Structures: Buildings and improvements
Occupancy: Uses of the structure or parts thereof
Infrastructure: Sewer, water, streets, and other utilities.

A GIS manages these data to take advantage of the obvious interaction and interdependency which exist among them---which is their occurrence in an area governed by an organization. However, the ability to do this depends on how the entities are defined and how those definitions are translated into digital formats. The industry should concern itself with providing clear explanations of the alternative definitions and the ramifications of choosing one or another.

3.1 The Land Base

Thanks to the National Academy of Sciences, the importance of a well planned cadastre is well stated and a set of basic standards for the content of such a data base exists. Procedures and Standards for a Multipurpose Cadastre is the best starting point for the planning of an urban GIS. It makes and explains the point that the land is the basis for all local government activities, and that this provides a basis for organizing local government information.

The report, however, does not provide sufficient detail to define the basic entities with which a government must deal. Definitions are prerequisites to solving the real problem facing local government cadastres. This is not the poor quality of maps, the lack of good geodetic control, or even the poor quality of cadastral information. These are symptoms of the real problem --- most local governments lack a system which controls the daily or hourly changes made to the land by multiple agencies, not just the appraiser or tax office. This lack of a system creates problems in defining the entities which appear so simple at first glance.

For example, the land base in local government is divided into 'parcels' which are not always equivalent to the tax parcel which is the only focus of most local government cadastres. One reason for this is that most governments do not require the recombination of parcels when a single structure is erected on several parcels. The tax office can deal with the issue by creating a single account number. This works for issuing tax bills, if it is not a high-rise condominium which is divided into 100 equal 'parcels' which share land value. However, how does an automated system present this 'pseudo-parcel' to Building Inspections, Zoning, Fire, or Police systems? Should one create 'pseudo-parcel IDs' for anomalies? Can the illogic built into our land control systems be changed by a local government? Can the changes be made retroactively?

A cadastre created for tax purposes is insufficient for most other local government activities. It is only one view of the land base. All views of the land base---cadastral,

planning, inspections, public works, police, fire--- should be included in the review of data to be included in the urban GIS. We need research on how to best deal with the illogic of existing land data used by local governments. The illogic does not disappear because it is difficult to automate and does not fit the logical data base design.

Once defined the data must be collected and maintained. The automation of a tax map is not a GIS which solves the problems of local governments. A GIS should address the processes which create the information which is only represented at one point in time on a map, automated or not. Accurate and timely data are more of a problem for local governments than mapping. Graphics is only one format for land data. It is a format which is used for only a small fraction of local government activities. The major processes which control and affect change to the land base are :

Zoning
Subdivision
Code Enforcement:
    Permits
    Inspections
Taxation
Planning
Deed Recordation

Each of these processes can change the cadastre, i.e. the quantity, value, and ownership of land. The relationships between the land and these processes should be one subject of GIS research.

Another land data issue I have found in local governments is a misunderstanding that a cadastre is concerned with just the land parcels which are part of the tax rolls. This is a reasonable mistake because this is the source of most revenue. However, is this tax cadastre all inclusive? It is not; because it is not, local jurisdictions do not and will not have a truly multipurpose cadastre. The missing land is composed of rights-of-way (ROW) which are usually defined (if defined at all) only as the land which lies between two or more parcels. Most local governments have no good record of rights-of-way even though the largest portion of local government's operational budget is spent in the ROW.

I have been unsuccessfully searching for a reasonable discussion of how local government views ROW. Most Public Works Departments deal with it as corridors between ownership parcels, unless they are purchasing additional acreage. The corridors are seen as block long strips, intersections, and all possible aggregations thereof.

This is a second issue with which the GIS industry must deal. How do we identify and systematically process land which falls in the ROW? Can it always be defined in terms of the tax parcel? Is it a separate parcel? If it is separate, where are its boundaries? What are logical units of ROW when one automates it? Is an intersection any area which is part of two or more rights-of-way? Is it an entity unto itself? The machine must be told precisely before we can solve the problems of work orders, sign and light

inventories, ROW purchase and vacation, and land subdivision. The industry should research the choices and provide clear alternatives, if not clear answers.

3.2 Beyond the Land Base

The cadastre does not stop once we can clearly identify what land is where. We must keep track of the value of that land. Value depends on: Natural features, proximity to desirable or undesirable features, parcel size, zoning (allowable use), actual use, structures, and improvements. Local urban government controls all but the first two variables. This control is exercised through the processes mentioned earlier. Those processes represent at least 50 percent of local government activity. The largest exceptions are the emergency services (fire and police)---government functions which protect the people and the property. These functions can all be part of a GIS. They manage local urban geography. This industry needs to research how that can be done.

Governments have the same kinds of problems defining structures and improvements as they do defining and maintaining land data. How can one address shopping malls or condominiums? All agencies or functions do not view structures or substructure units the same way. How does a GIS distinguish between land uses and building uses in a mixed use development on a parcel with multiple zoning types? How do you track the acreage of zoning types and land uses to comply with local or state laws when one parcel can have several zoning or use classifications? To where do you dispatch an ambulance or a fire truck on a multi-building development before addresses are posted or even assigned?

Can the GIS industry continue to ignore these very real, very significant questions by simply making and selling more maps? Yes, it can. However, to do so is irresponsible and will result in a backlash from the clients you need to keep.

GIS research should include alternatives for defining structures and substructure units for use by all local government functions. Government functions which manage and protect these structures and occupancies should be studied to determine the affect of the alternatives on operations.

3.3 The Infrastructure

The public infrastructure is the last major component of the urban GIS. We own it. We are responsible for it. We spend billions maintaining it. Can we tell you what and where it is? In most instances, no. Our largest public investments are poorly defined and usually ignored until their is a problem.

The inclusion of the public infrastructure in the urban GIS provides an opportunity to solve numerous issues concerning capital improvements planning, development

control, work order processing, and protection of public health and safety. The primary infrastructure networks are:

Streets
Sanitary Sewer
Potable Water
Storm Drainage

The inclusion of the infrastructure in the GIS must be more than mapping the networks on a graphics system. The problem of clear definitions for the components of each of the major infrastructure networks is as essential for these data as it is for the land base.

Streets serve as an index to the urban environment. It is our frame of reference for locating anything. The U.S. Census Bureau proved this with the DIME data structure which works well as an urban geographic base file when it can be properly maintained. One reason local governments did not maintain their DIME files was that the maintenance effort was more costly than the value of the automation. Statistical analysis is not as important to local government as the provision of primary services like: water, sewer, transportation, and code enforcement. People needed more information and the technology was unable to provide it. In the case of the public infrastructure, this is still true.

The need for more and better information is driving a boom in the public works sector. However, the importance of maintaining data is only increased when that data becomes more complex. Standards and definitions are essential. What are the units of pavement which will be defined? How does one reference work done to the pavement? By address? which side of the street, which address in a three block work area? which address in an intersection? If you do not use address, how do you send someone to the site of a street project? There are many answers to each question---we have to research the ramifications of selecting one over the other, or the cost of using them all. We must present the alternatives to the people who must make the decisions---the local government.

Sanitary sewer and potable water systems are very important to the urban environment. We regulate them, design them, build them, and maintain them. The inclusion of these networks in the urban GIS can have an impact on large portions of the jurisdiction's budget and work force.

The problems of definitions of pipe network components is very significant to automation. All pipelines are not the same to a data base management system. The relationship between a water system and a manhole which contains a pipe line component such as a valve, is different than the relationship between a sewer pipe line and a sewer manhole to which the pipe is attached. The first manhole is a container for a component of the network, the second is part of the network and can be used to regulate flow. The people who work with these manholes know and can work with the differences; a machine must be provided with the same knowledge if we want it to work with these networks effectively.

Another issue with many alternatives is similar to the one described for street maintenance work, i.e., how do we reference locations which are not address specific; where do we send our crews? With pipes the problem is different because they are underground. What are the alternatives for referencing underground utilities to visible references? We cannot send a survey crew with every water repair crew.

What are the definitions of the basic components of the urban geographic information system? Do these definitions make it possible to provide information to all of the people who deal with those components? What are the data processing ramifications of using one definition or another? These are basic issues which should be addressed by the industry through objective research in local governments.

4. GIS DATA PROCESSING

The GIS can be a comprehensive approach to data management in local government. It can also be a series of independent systems, each requiring data processing maintenance and support. What are the data processing requirements for an urban GIS? What is the life-cycle for GIS hardware and software? Do graphics systems have the same life-cycle as other types of systems? What are the implications of the answers to these questions on the cost of data processing in local government?

Good, reliable research on these questions would save local governments, and thus taxpayers, tens, even hundreds of millions of dollars. Local governments are at the mercy of vendors' enthusiasm and ignorance at best. Good research will help us all by improving decisions and providing measures for comparison.

5. THE REAL URBAN ISSUES: OPERATIONS AND APPLICATIONS

The issues concerning the data which are part of a GIS are only half of the problem which faces this new technology. The data become information only after they have been processed for specific applications. An organization must examine both parts of the problem before it begins to develop a geographic information system. The questions are:

> Which of these basic data should be automated as part of their GIS;
> How is the data created and recorded?
> How and by whom is it used and maintained?

These are not questions which depend on the technology selected. They depend on the organization's understanding of its responsibilities, goals, and processes. These are the kinds of questions which prevent the implementation of GIS in local government because they require difficult decisions without pat answers. It is much easier to come up with data definitions.

This section deals with the two major applications which I have found driving GIS development in local government. Research on the role of these applications in local government GIS would be extremely useful to the majority of local governments and to the industry as a whole.

5.1 Land Development

Land development, or redevelopment in older communities, highlights the value of GIS in local government. It is through the land development ordinances and regulations that local government tries to control local geography---the way we interact with our urban environment. The purpose of land control laws is to provide a good place for living. The intended interaction among many ordinances and processes is supposed to be a "geographic information system," designed by multiple committees, at different times, with different intentions. When it works, it works by brute force. A good series of research papers on the land development application and GIS would be enlightening to the GIS industry, and to those governments which are trying to improve the service they provide.

It is difficult to select a starting point for development control because it varies in time and space. However, one of the starting points is the subdivision ordinance. This ordinance and its implementation control the land parcels and right-of-way. The other starting point is the Zoning ordinance and its implementation. These are keys to the control of land development. It is here that requirements for infrastructure needs and community improvement concessions can be made. It is here that the community imposes its will on development. However, most of the conditions which are set at this stage are enforced by the building inspectors who have no knowledge that these conditions and require-ments exist. How can GIS use the obvious link between the processes to insure enforcement of the law? How can a system track development plans through a multi-year, multi-named project which changes owners? How can government track the public safety requirements peculiar to a site through the planning and building process? The links are geographic---land and the various ways we describe it. These include: site, project, planning area, parcel ID, address. The location does not change, but the land and our views of it change frequently. Research on how these processes work as a GIS is important.

Land is the base for a GIS, however, structures and their occupants are the primary responsibilities of local government. The building code and its enforcement is one of the primary applications in local government. It affects the safety of people in our homes and public places. It is an application which is responsible for the enforcement of almost all land development law because the inspector in the field is the only person who sees what is being built. How can we link this process with all of the preceding and succeeding processes so that the law is enforced? Again the one link is location.

Location provides the key to the following questions asked by governments on an

hourly basis: What uses are allowed on a specific parcel? What building codes apply to those uses, in that place? Where something is being built is the only link between local ordinances which are incredibly interdependent. Research to explain the interactions and the possible choices for automating them would save many dollars, and help make our cities more habitable.

After something is built the land development control process turns it over to ordinances which govern the use of the structures. The primary use control ordinances are for health and fire prevention. It would be useful for the industry to examine these applications and offer some explanation of ways to improve the geographic information available to these agencies which protect us day in and day out.

5.2 Infrastructure Management

The infrastructure inventories mentioned above require management whether they are automated or not. The issues for GIS research are in three basic areas:

How are CAD/CAE linked to the GIS?
How do we keep inventories current with work orders?
How can we base Capital Improvements Planning on reality?

Computer-aided design and engineering of the public infrastructure could be done in a way which made it possible to turn planning data into operational data when the construction passes final inspection. Inspections could be linked to all of the other development issues in other government agencies. These plans could take advantage of good right-of-way and parcel data. I am suggesting this as a good research topic even though I know that there are vendors who are trying to create the technology now. I am making my suggestion because the GIS user should have some say in the direction of that development.

Work order management systems should be more than people management systems. Every action changes the public infrastructure and should influence the way we deal with it. Location and spatial relationships are the keys to tracking maintenance activities and understanding the condition of the infrastructure.

Capital improvements planning (CIP) and budgets are of great interest to local governments. Most CIP budgets are based on guess work which is based on last year's budget. GIS can put the real information at the hands of decision makers. GIS can take advantage of the fact that necessary public improvements depend on land development, and the capacity and condition of existing facilities. What are the alternatives for doing this?

6. THE RESEARCH AGENDA

There are more questions than answers in this discussion because research has been

controlled by a very small group. This group has brought the technology to a point where it must now become responsive to the users. It is in everyone's interest to educate ourselves and the users in the application of the technology. A major portion of our research budgets should be spent on the study of local government applications. The industry as a whole--academic, government, and private enterprise--must take the time to define the problems and plan for solutions, or 'geographic information system' will become a term for meaningless hype and this industry will continue to sell technology without solutions.

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[1]NATIONAL ACADEMY OF SCIENCE, 1984, Procedures and Standards for a Multipurpose Cadastre;

GLOBAL SYSTEMS

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CONNECTING GLOBAL SCIENCE THROUGH SPATIAL DATA AND INFORMATION TECHNOLOGY

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1. INTRODUCTION

It is interesting to note that, in today's society, news about the global environment can easily make headlines. We are becoming aware, collectively, that the environment of our planet is changeable -- by human activities and by natural processes; and, there is a growing interest in understanding how global systems affect life.

In this paper, we will begin by tracing some of the origins of our new global awareness, and then show how these trends can be used to predict what global systems science will require in two vital and complementary areas: (1) information systems; and (2) the process of handling digital information. We will then describe the role and activities in global geoscience which we are developing at the National Geophysical Data Center (NGDC) in Boulder, Colorado, in regard to our national responsibilities and international involvement as one of the World Data Centers of the International Council of Scientific Unions (ICSU).

2. ISSUES

The issues which have started us thinking globally are familiar to most of us -- climatic change, desertification, deforestation, loss of biological diversity and natural resources, greenhouse warming, changes in the protective ozone layer, nuclear and non-nuclear energy; and today, even the global banking system is recognizing that environment and economics are inseparable. Such issues, reinforced by the psychological impact of seeing our planet from space, have spawned many concepts of human unity and connectedness, which now appear in popular literature. Recently, the U.N. Commission on Environment and Development completed its report, which calls for a fresh look at human activities focusing

on the idea of "one world," and new thinking in terms of "sustainable development," globally.[19]

In recent years, we also have become aware of potentially significant natural changes which may affect life as we are used to it. We have discovered that our sun is a slightly variable star which may cause changes in the earth's climate, and that the climate system itself is very intricate and changeable. We have discovered that the Earth's biogeochemical cycles are all linked, and that human activity can, and already has, altered them significantly. There is thus a growing interest in "global change", cycles and interactions, from the standpoint of Earth's natural life-support systems.[5,17,18]

Global interdependence and environmental pressures are increasing, along with the need for collective solutions. Still, the truth is that even the experts do not adequately understand the changes that are taking place right now, and are at a loss to predict what might result from human activity and natural change. It is likely that we are seriously unprepared for the changes ahead -- changes that we may already be committed to --, and it is vital that we seek a better understanding of our own activities, as well as the systems of this unique planet on which we live.[2]

3. PROGRAMS

There has been a growing response to the concerns mentioned above. New programs are emerging which are aimed at achieving a greater understanding of whole systems, rather than just their parts. These programs will be highly interdisciplinary in nature, and will depend on parallel research that is interconnected in a more "real-time" mode than has ever been attempted before.[16]

The International Geosphere-Biosphere Program (IGBP), which was adopted by the ICSU last year, is an unprecedented effort in international scientific cooperation aimed at studying all aspects of global environmental and ecological systems -- their functioning, response to man's activities, and natural changes.[5,8,14,15]

Already, national programs have formed in accordance with the IGBP. Three of the major U.S. scientific agencies, the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), and the National Aeronautical and Space Administration (NASA), recently announced commitments to study global change by formally endorsing the report of NASA's Earth Systems Science Committee.[3] The heads of each of these agencies called for cooperation in the study of global change and pledged their support. NSF and NASA have formally established and funded global studies within their organizations. The NASA program is

called the Earth Systems Science Program, and in NSF it is called the Global Geoscience Program. NOAA has established the Climate and Global Change program and is seeking funding for it in 1989. In addition, other government agencies including the US Geological Survey (USGS), Environmental Protection Agency (EPA), and Department of Energy (DOE) are implementing global studies programs. The U.S. National Academy of Sciences' National Research Council has established a Committee on Global Change, which will be the U.S. National Committee for the IGBP; and similarly, eleven foreign countries have already established such national committees.

Four U.S. federal agencies (NOAA, NASA, NSF, and USGS) have formed an interagency working group which is specifically addressing the problem of data management for global studies.[9,4,13] Also, ICSU has asked the International Geographical Union's Research Development Committee to examine the progress and problems in the design and implementation of global digital databases of geographically referenced earth descriptive data. This issue of data management has been identified as perhaps the single most crucial aspect of these new global programs.[15]

A central idea behind the IGBP and related programs is the study of whole systems, or "Systems Science". While this is not a completely new concept, it is true that the methods of research on whole systems have yet to be established. This point is most relevant to those of us concerned with Geographic Information Systems (G.I.S.), because we are actually involved in developing the instrument that will be used in new, data intensive, scientific methods.

4. TRENDS

By most predictions, we are approaching a period of major global transition for human experience generally, and it is this prospect which is now being reflected in new concepts for global science. Current developments in the methods and assumptions of global "systems" science are not isolated from other developments in society and the human psyche. Thus, a greater insight can be gained into the scientific and technological changes that are occurring, by considering them together with the growing planetary awareness and drive toward cooperative processes.

Technologically, the emerging era will be characterized by an extremely high volume of digital information, sophisticated systems to deal with it, and global cooperation among those collecting, managing and using this information. It will require cooperative structures, integrated tools, and a new form of scientific communication based on the exchange of digital information in the form of "data sets" between studies that are linked in parallel.

	I PHENOMENON	II RESPONSE	III RESULT
SCIENCE	Global issues	New programs	New theory
	Climate change	IGBP	Holistic theories
	Resource loss	Systems research	Systems theory
	Population/famine	Earth Observation	"Gaia" hypothesis
	World development	Interdisciplinary	Cooperation theory
	World economy	synthesis	System behavior
METHODS	Technological explosion	Instrumentation/ Visualization	Experimental study of whole systems
	Remote sensing	Observing systems	Prediction/testing
	Data acquisition	Integrated GIS	Parallel research
	Data processing	Data technologies	Research linkage
	Data storage	Representation/ modeling	Technical language
	Communication		
PSYCHE	Psychological expansion	Cooperation	Understanding/ Awareness/Policy
	"One world"	Scientific Social/personal	Global knowledge
	"Global brain"	Institutional	Mutual awareness
	"New age" ideas	International	Joint solutions

Figure 1. Multilevel trends in the evolution of global geoscience.

In this section we will attempt to show that global trends are connected, and highly predictive of the kinds of activities which we must emphasize in developing a truly appropriate science of the Earth. Our particular interest here, is what will be required in terms of data, information systems, and cooperation. As we become convinced that a very real and very significant change is taking place, it then becomes apparent that those involved in information technology, in all areas of systems development, digital information, applications, policy, and management, are vital colleagues in an important global enterprise.

Figure 1 shows a process of natural development which can be traced within three levels of human involvement (shown vertically on the left) -- the scientific, the methodological (or technical), and the psychological. Advancement is shown as a three stage process (from left to right) moving from events, or phenomena (level 1) to mechanisms of response to these events (level 2), and finally leading to a new result of some kind (level 3). There are two important aspects of this matrix. First, one can immediately

see that, at all three levels, the same trend is represented, that of growth toward greater integration and cooperation, and perhaps eventually, new policies which may offer mutually acceptable solutions. This is one of the assumptions on which the diagram is based; predicated on the developments which have been observed so far, and a growing theoretical basis.[1] Second, it should also be apparent that progress from one stage of development to the next, at any level, would be impossible unless all 3 levels are sufficiently integrated.

For example, it would be inconceivable that the new programs shown at stage 2 could emerge from the pressing issues shown at stage 1 without the presence of the technological explosion we are witnessing and the presence of an expanded psychology manifested in global thinking -- the other parts of stage 1. Similarly, it would be equally impossible to move into a truly new way of operating scientifically (stage III), until all of the parts of the stage before it are in place and functioning smoothly -- that is, the new programs, new instrumentation, and the cooperation and connectivity that will allow these integrative programs to work.

At the present time, all three levels of stage 1 are becoming integrated, and this is allowing us to move ahead into stage 2, where we see the advent of global systems research programs such as the IGBP. The concepts embodied in the IGBP and related programs are forming the basis for a new science of integrated systems, which will eventually fill in the box at stage 3. But, as just described, we can predict that this science and whatever benefits result, will require that the new programs be combined with a true technological integration that produces the needed scientific instruments and data handling, and with cooperative mechanisms that will form the necessary linkage.[11]

5. MODELING AND TESTING

In order for global systems science to become functional, there must be the equivalent of an instrument for objectively visualizing ecosystems and regional patterns in terms of selected variables. This is critical for a science of whole systems, and it is our greatest challenge for integrating G.I.S. technology. As such capabilities develop, we will enter the realm of experimental science, where hypotheses about whole-systems phenomena can be formulated and tested in an operational time-frame short enough to affect policy. Such developments may have an impact on environmental science similar to that which the microscope had on cell biology.[10]

Modeling in a G.I.S. can be distinguished from other types of models. For example, simulation models, such as General Circulation Models (GCMs) used in climate studies, are designed to repre-

sent current theory. "Testing" hypotheses within simulations can help determine their reasonableness in regard to current theory -- a step that is very important in the scientific method --, but empirical tests must rely on comparison with observed data. Although some simulation models, such as GCMs, have provisions for empirical comparison, they are rarely designed to optimize this process. A G.I.S. model, on the other hand, is not a simulation but a representation of the system itself -- much the way a photographic image is a representation of an object. By design, a G.I.S. representation is independent of theory, and thus well suited for testing through calculation and visual interaction. Importantly, G.I.S. technology can be used to integrate empirical data and generate predictive data. This has further advantages in facilitating the intuitive and creative human processes critical to scientific methods. Prior to this, there has been no means to adequately represent an ecosystem for experimental purposes.

5.1. A scenario for modeling

The maps shown in figures 2-6 represent a G.I.S. mapping exercise performed for NOAA's Geophysical Monitoring for Climatic Change program. The data presented are preliminary calculations and not the final results which will evolve as the project is completed.[6] Nevertheless, we are not reporting on the study itself, but the methods employed, which demonstrate some aspects of how G.I.S. can be used in "interactive modeling."



Figure 2. Soil erosion by Major Land Resource Area.

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The first map, figure 2 above, shows soil erosion based on data from the Soil Conservation Service (SCS), averaged according to the Major Land Resource Areas (MLRA's) defined by the SCS. There is some justification in stratifying the analysis this way, rather than in a regular grid, since much of the data were only available according to MLRA units and the MLRA's are defined according to homogeneous soil and land-use characteristics.

The project was aimed at modeling the amount of calcium that becomes airborne in wind eroded dust, which is hypothesized to have an effect in neutralizing acid precipitation. Variables which went into the model were stored in an attribute file, as were variables which resulted from model calculations at various steps in the analysis. Sample attribute information is shown in table 1 below.

Each variable was classified into 8 classes using commercial spreadsheet software, and the resulting choropleth map was produced by using predetermined shading and color assignments. We can thus see individual steps in the modeling process.

ATTRIBUTE	DATA FOR EACH MLRA UNIT ---->		
MLRA UNIT #	10	100	102A
DUST FLUX	0.0000003330	0.0002817705	0.143124922
DUST FLUX CLASS	1	4	7
EROSION	0.0000005114	0.00111764691	0.0365214073
EROSION CLASS	1	4	6
WIND RATIO	0.00712306478	1.1969730527	0.67810170221
WIND CLASS	1	6	5
SOIL CALCIUM %	2.05280	0.34803	1.06687
SOIL CA. CLASS	5	2	3
ENRICHMENT	1.6326	3.0131	1.4323
ENRICHMENT CLASS	1	2	1
CA FLUX	0.0000000112	0.0000029548	0.0002187060
CA FLUX CLASS	1	3	6

Table 1. Sample Attribute File for Calcium Flux Study

A wind model was applied to the erosion data to predict how much of the eroded material remains airborne as dust flux (figure 3, below).



Figure 3. Dust flux by Major Land Resource Area.

Measured values of calcium percentage in the soil (figure 4) were corrected for differences induced by their dependency on eroded particle size, using an "enrichment factor" (figure 5).



Figure 4. Calcium percentage in soil.

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Figure 5. Enrichment factor for calcium percentage.

Finally, the predicted calcium percentage in dust was combined with dust flux to produce a prediction of calcium flux (figure 6).



Figure 6. Calcium flux in the atmosphere by Major Land Resource Area.

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This procedure demonstrates several interesting concepts, similar to those employed in raster image processing. One is "interactive modeling," where the scientist is allowed to view each stage of the modeling process and apply his intuitive and reasoning abilities -- abilities that computers are not able to duplicate. Intuition, which generates hypotheses and forms hunches, cannot be reduced to a mechanical or logical process. The most important work goes on in the human mind, and modeling systems should be designed to maximize the interaction between mind and machine. Logical testing, however, lends itself more to full automation, as does the process of operationally classifying patterns with the help of "artificial intelligence."[7]

A scientist creates by intuition and reason, and then tests by logic. In both areas, G.I.S. methods are appropriate. Interactive display techniques employed by G.I.S. have proven their ability to aid human creativity in forming hypotheses, modeling system parameters, and judging "reasonableness". Empirical data bases within the G.I.S. also allow testing and verification.

Many "black box" models, particularly those which use recursive calculations to represent changes through time, tend to bury predictive data within the model as run-time inputs. They thus suffer from unreasonableness and do not interact well with human capabilities.

Another lesson in this project was the value of the spreadsheet type functions integrated with G.I.S. Spreadsheet software in general has been extremely successful due to its ability to play "what if." Now imagine this linked to cartographic output in an interactive modeling process such as described above. If the classification and shading functions were automated, we would have an extremely powerful tool for near "real-time" analysis of environmental patterns. Although demonstrated in principle, this capability is not implemented in current G.I.S. packages.

6. INFORMATION SYSTEMS

NASA's Earth Systems Science report, now endorsed by other agencies as well, calls for "an advanced information system to process global data and to facilitate data analysis, data interpretation, and quantitative modeling of Earth System processes by the scientific community."[3]

It is now apparent that information systems and the data that they manage are inseparable and must grow up together. Both data and systems must be designed to work together. Systems must be designed to handle diverse applications, and data bases must be designed for their intended use.

A concept whereby G.I.S. becomes fully integrated with other software seems especially necessary for the wide variety of functions that will be called for within the overall data system. Based on our experience using G.I.S. for data center functions, we have determined some preliminary functional requirements for such "integrated G.I.S." for global data management in the geosciences. These requirements are:

1. Complete raster and vector functions
2. Vector to raster, and raster to vector conversions
3. Multiple cartographic projection capability
4. World coordinates interpreted correctly for any projection
5. Global scales with acceptable precision for local resolution
6. Random or gridded point data entry
7. Gridding in various projections
8. Contouring from gridded data
9. Attribute support and high-level, relational DBMS linkage
10. Vector and raster data search and editing
11. "What if" modeling (spreadsheet functions)
12. Classified output by attribute with pre-assigned color and shading
13. I/O conversions for all major data formats
14. Functional integration with DBMS, Image processing, statistics and statistical graphics, spreadsheets, artificial intelligence and expert systems
15. Communications and remote data access
16. Error analysis and documentation
17. High level language interface for programmed operations

The tasks to which such a system would be applied include:

A. Storage and retrieval of summary data
B. Registration of information from various sources, scales, and structures
C. Quality control and management of all spatial data (including data integration and analysis)
D. Output for monitoring activities
E. Modeling and predictive outputs
F. Statistical testing of model predictions with empirical data
G. Rapid communication via exchange of data sets

With the great demands that will be placed on advanced systems, they must continue to move toward greater functional integration and inter-system compatibility. "Low-end" systems must be compatible with production systems so that data products can be transferred easily to users; and these systems must also be compatible with each other so that information can be easily exchanged between parallel activities.

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6.1. Data management systems

Nearly all vector G.I.S. were originally designed for resource management, civil engineering, or urban planning applications. Raster systems have been designed primarily for image processing and resource analysis. What is needed in the emerging global geosciences, however, are systems designed specifically for global data management.

For example, a primary use of G.I.S. in data management will be for quality control of data. This is essential before integration of data sets can proceed. Figure 7, below, shows a shaded slope map of a portion of the 30 second point elevation data distributed by NGDC. Displays of this nature reveal large-scale errors such as the square-like depression and linear discontinuities in Colorado's San Louis Valley, at the lower-right portion of the frame, probably resulting, in part, from a datum shift during the original digitization of the 7 1/2 minute quad.



Figure 7. Shaded slope map of 30-second point elevation data showing erroneous linear and square discontinuities (produced by Peter Sloss, Marine Geology and Geophysics Division, NGDC).

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Other errors, such as erroneous holes or spikes, can also be easily revealed. This kind of display technique, combined with editing capabilities, is a basic tool for any data center. Beyond that, however, it is feasible to develop methods to compare various data sets with each other or with calibration sets, and, with appropriate projections, to overlay data sets with published maps. At a further level of sophistication, it should also be feasible to provide functions for subsampling data sets and/or integrating data sets from different scales.

6.2 Inventory systems

We have been investigating the use of G.I.S. for data inventory purposes, and have created a pilot global aeromagnetic data inventory. Coastlines and country boundary data from the World Data Bank-II were used to provide a background reference, shown in figure 8 below.

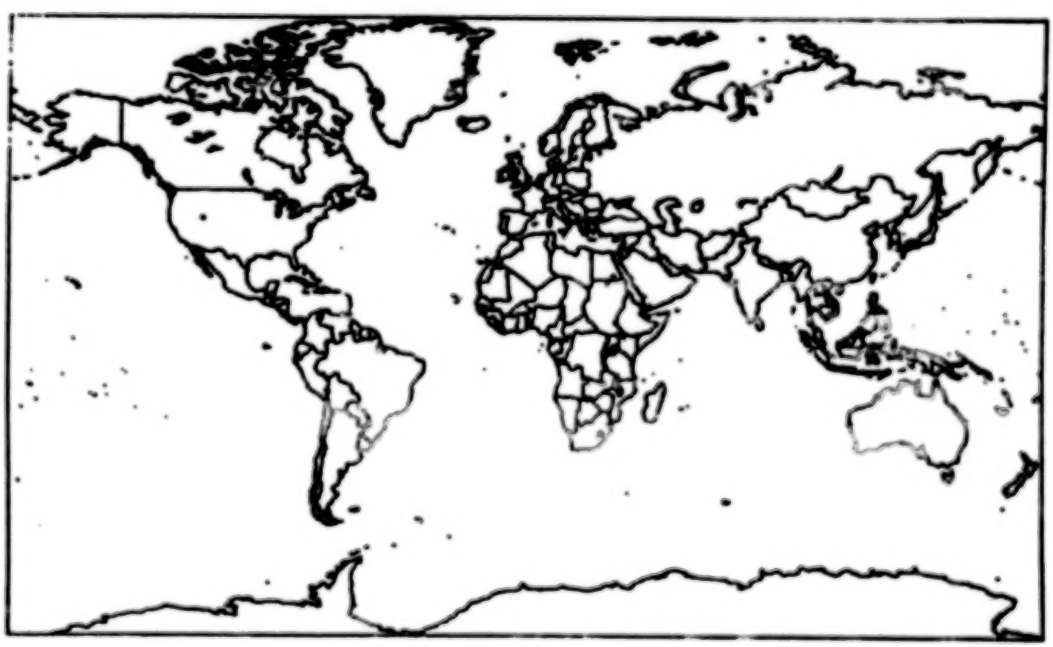


Figure 8. Base map for aeromagnetic inventory (Miller's Cylindrical projection).

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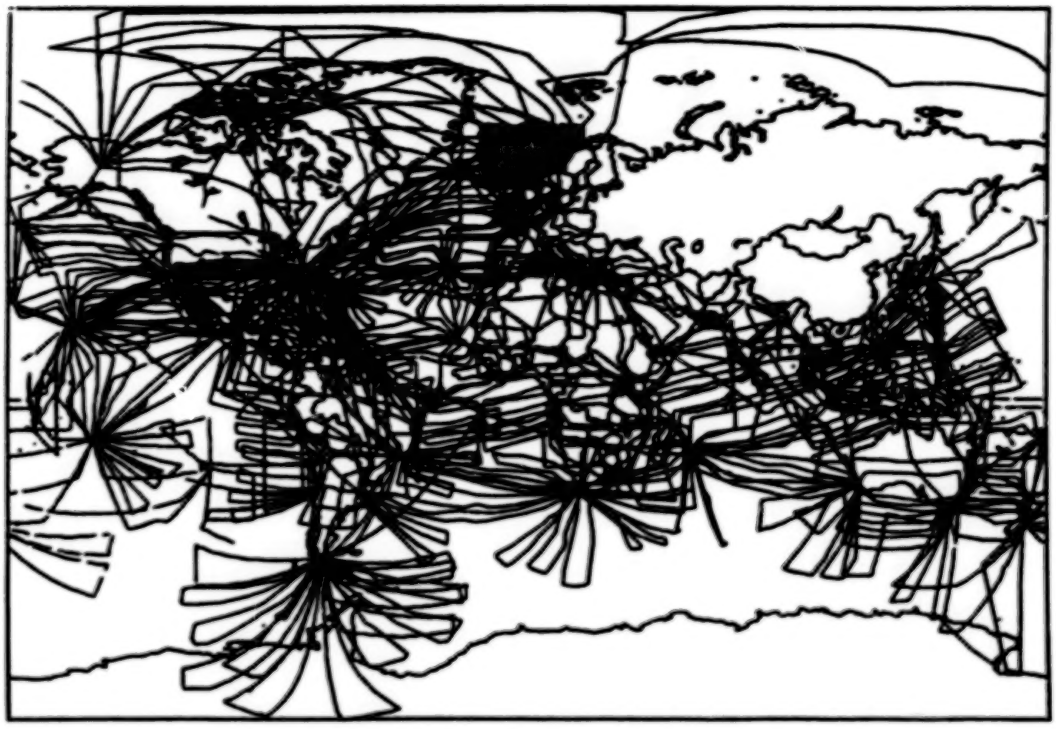


Figure 9. Global aeromagnetic flight lines (Miller's cylindrical projection).

The flight line navigation data were sampled at a ratio of about 100 to 1 to produce a global inventory of the flight paths. The generalization procedures used a modified triad algorithm to reduce the number of navigation points. A portion of this inventory -- the Project Magnet database -- is shown above in figure 9, which represents less than a quarter of the inventory. The complete aeromagnetic database contains 37 million observations from 286 surveys, covering 3 million flight line miles. The information is stored on 370 computer tapes holding 3 gigabytes of data.

---KEY----	---DESCRIPTOR----------
FLT_LINE	SURVEY FLIGHT LINE IDENTIFIER
CREAT_DATE	GENERALIZED FLIGHT LINE CREATION DATE
MEAN_ELEV	MEAN ELEVATION FOR SURVEY FLIGHT LINE
MEAN_MAG	MEAN TOTAL MAGNETIC FIELD FOR THE FLIGHT LINE
STDEV_MAG	STANDARD DEVIATION OF THE MAGNETIC FIELD
MIN_MAG	MINIMUM MAGNETIC FIELD VALUE FOR SURVEY FLIGHT LINE
MAX_MAG	MAXIMUM MAGNETIC FIELD VALUE FOR SURVEY FLIGHT LINE
SAMPLES	NUMBER OF SAMPLE POINTS FOR FLIGHT LINE ARCHIVED
THATATTR	LENGTH

Table 2. Examples of attributes in the aeromagnetic flight line inventory

The attribute capabilities of the system were used to provide statistical and labeling information, as well as to provide complex Boolean search and retrieval functions on flight line data. Table 2, above, shows 9 of the 24 variables created in the attribute file.

By creating an inventory in this manner, we have available the normal G.I.S. capabilities for geographic searching and windowing, plus the ability to search and select by attribute. For example figure 10, above, shows a sample retrieval by Boolean search for flight lines with a high average aeromagnetic total-field strength. As one would expect, flight lines are retrieved in the vicinity of the geomagnetic poles.

This project was successful in demonstrating the G.I.S. potential, but not in making the inventory operational. The missing elements were (1) a high-level language interface to set up smooth and friendly operations for non-technical users, and (2) speed of retrieval, which is sacrificed for analytical capabilities in a G.I.S. Variations of the G.I.S. concept, streamlined functions, and perhaps integration with other methods, could solve these problems.

Global databases, such as the aeromagnetic database described here, will grow to such size in the near future that even summary and inventory information will require such special-purpose G.I.S. functionality.



Figure 10. Search for flight lines with high average aeromagnetic total-field strength.

7. DATA SET TECHNOLOGY

Equal in importance and complexity to the development of appropriate information systems for global science, is the process of designing, processing and managing data sets for integration, synthesis and communication within the geosciences. This process, unlike the G.I.S. technology that will make it possible, does not have a name yet. We propose the term "Data Set Technology" (DST), for reasons that should become obvious. The challenge of this technology will be to use digital information to develop a new form of scientific communication or technical language that will connect global science.[12]

The current status of DST/GIS activities at NGDC/WDCA in Boulder is represented in table 3, below.

- o Tabular (DBMS) inventory systems (operational, R&D)
- o G.I.S. inventory systems (pilot system, R&D)
- o Data set quality control and integration (R&D)
- o Format conversion software for G.I.S. data exchange (R&D)
- o Global paleoclimatology database (planning and evaluation)
- o 10 minute global environmental reference database (planning and evaluation)
- o 16 Km AVHRR global vegetation and temperature indices linked to the 10 minute database (proposal)
- o Digital global environmental atlas (R&D, proposal)
- o Global reference databases (evaluation, workshops, proposals)
- o High resolution topography for world conservation inventory (proposal)
- o On-line reference and dialog system for global change data (proposal)
- o G.I.S. enhancements for DST (R&D, proposal)
- o Joint projects (agreements, proposals)
- o Facilitation and coordination (resolutions, agreements, working groups)
- o National and international assistance (projects, proposals)
- o Reimbursible projects in remote sensing, G.I.S., and data management (projects, proposals)
- o Initiative for 1989 "Climate and Global Change" program (proposal)

Table 3. Projects and activities in Data Set and G.I.S. Technology.

If G.I.S. are to be used in sophisticated methods of interactive modeling, prediction, and testing, then two types of data will be valuable. These are (1) empirical, or observational data, and (2) predictive data resulting from models. Furthermore, if the trends we outlined previously are valid, then "systems science" for global studies will involve parallel research that is linked laterally through the exchange of digital spatial data sets (at appropriate time sequences). These data sets will have to be specially designed for such studies, and for use in advanced, integrated G.I.S. Thus a new form of scientific exchange is envisioned that does not wait for the time consuming process of linking studies sequentially. This connectedness of studies will depend on "Data Set" and G.I.S. Technology."[10]

7.1 A global digital environmental atlas

REFERENCE DATA (dt > 25 years)
o Elevation and bathymetry data, merged from 10′ and 5′ data
o Terrain characteristics (number and direction of ridges, terrain classifications)
o WDB-II boundary files
o Coastal elevation and bathymetric contours
ENVIRONMENTAL DATA (dt = 5 years)
o FAO soils (Dominant, associated, slope, texture, phase)
o Nitrogen, carbon, ecosystem and cover classifications
o Average annual land and ocean surface temperature
o Average annual rainfall and insolation
o Agricultural, land use, and urbanization data
o Percent water
o Vegetation index averages from AVHRR 16 Km global area coverage (GAC)
o Sea height and ocean flux averages
o Permanent ice thickness
ANNUAL THEMATIC DATA: (dt = 1 year)
o Rainfall and temperature summaries (annual and monthly)
o Vegetation index summaries (weekly)
o Insolation, and cloud cover summaries

Table 4. A proposed Global Digital Environmental Atlas at 10- to 30-minute resolution.

Data set developments must be linked closely with their intended use and systems design. Discussions are progressing on specific criteria for reference and thematic data, and it will probably be several years before definite criteria emerge for basic data requirements. Still, it may be useful at the present time to produce an initial compilation of global data for general purposes and as a pilot exercise. Thus, using G.I.S. for integration, a "Global Digital Environmental Atlas" could be compiled without great difficulty, using data sets currently available from various sources. The final product could be distributed on CD-ROM or other suitable media.

Considering the purpose of such development, it would seem natural to organize the atlas according to the time-scale of change for the variables represented. This idea is presented in table 4 (above) with the approximate time scales spanning 3 orders of magnitude.

8. CONCLUSION

Global science trends toward holistic studies and applications will require new methods of conducting environmental research and analysis. These methods will grow out of two complementary areas of development: (1) advanced, integrated G.I.S. related software and hardware, and (2) "Data Set Technology," which is the process of planning, developing, managing, and exchanging digital information in a form that will comprise a new language for lateral scientific communication among global geoscience activities. As a "new age" in geoscience develops, many forms of connectivity will become vital. In addition to technological linkage, then, there will also be the requirement for cooperation and communication among scientists, system developers, policy makers and managers.

In addition to providing essential products and services, we at the National Geophysical Data Center and World Data Center-A in Boulder, Colorado, are willing to will serve as facilitators of various forms of international and national coordination activities in regard to data and information management. Because we recognize the vital need for broad-scale interaction in developing information requirements and standards, we strongly invite dialog and feedback, in addition to the efforts we have initiated.

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A WORLD SOIL HYDROLOGY FILE FOR GLOBAL CLIMATE MODELLING

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ABSTRACT

A soil data file containing 15,413 records was compiled from the Food and Agricultural Organization Soil Map of the World, 1:5,000,000. Each record is for a 1 degree x 1 degree latitude and longitude cell, which characterizes dominant, associated, and included soil units according to FAO taxonomy. Surface texture, slope, profile properties obtainable from the soil unit, and auxiliary information also are included. Because the file was intended to be used to trace soil-atmosphere moisture and energy exhanges in climate modelling experiments, soil-hydrologic parameters were stressed.
Coupling this information to other ground surface components permits a numeric solution of the hydrologic continuity equation for a one degree cell.

1. GROUND HYDROLOGY AND GLOBAL CLIMATE MODELLING

Numerical simulations of the effect on global and regional climate change caused by increased CO_2 levels in the atmosphere, resulting mainly from the burning of fossil fuels, indicate that the magnitude of temperature shifts are comparable to those experienced by the earth during past geologic eras. The development and improvement of global climate models (GCM) require refinements of model representations of physical processes and more detailed accurate prescriptions of real world data. Simulations of moisture and energy exchange between the ocean-land surface and the atmosphere have emphasized the role of the global ocean because of its greater areal extent and the uniformity of its atmosphere-free water interface.
The more complex land-atmosphere interface hydrology has been treated by a simplified one or two layer water bucket sub-model. As the GCM state of the art moved from a scenario output resolution of an 8^o x 10^o grid box to a 4^o x 5^o box or even, possibly to a 1^o x 1^o box (for local impact evaluation), the need to incorporate into the model more detailed ground surface geographic hydraulic variability was recognized.

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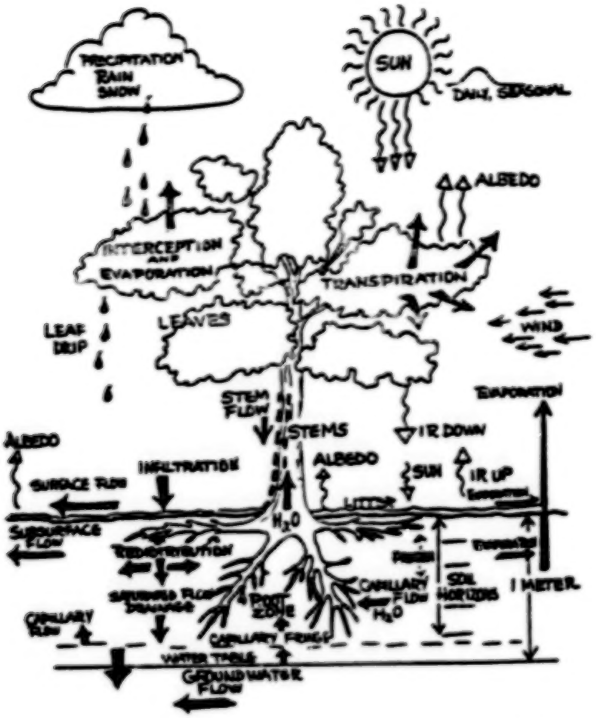


Figure 1. Atmosphere-ground hydrology energy-moisture interface

2. PARAMETERIZATION OF GROUND HYDROLOGY

The inclusion of realistic ground surface hydrology parameters in global climate models improves the sensitivity of simulation experiments of energy and moisture exchanges between the land and the atmosphere. Model inputs require geographic data on four land surface components: soil, surficial geology, litter, and vegetative cover. Of these, the soil is the major partitioning agent of moisture receipts because it strongly influences infiltration, runoff, storage, drainage, and, in addition, the plant and litter ground cover development. (figure 1).

The object of a geographic information system (GIS) is to provide input to GCM about the location and unique properties of each spacial entity. The analytical model then operates concurrently on the unique properties and the location of each entity. The governing equations are applied to each entity or to a synthesized group of like multiple entities selected according to explicit criteria. The sensitivity and the resolution of the model reflect the interaction between the size of the space unit and the representation of the physical process (Eagleson, 1982). The latter falls in the domain of atmospheric physics and ground surface hydrology. The former, clearly, is the business of GIS.

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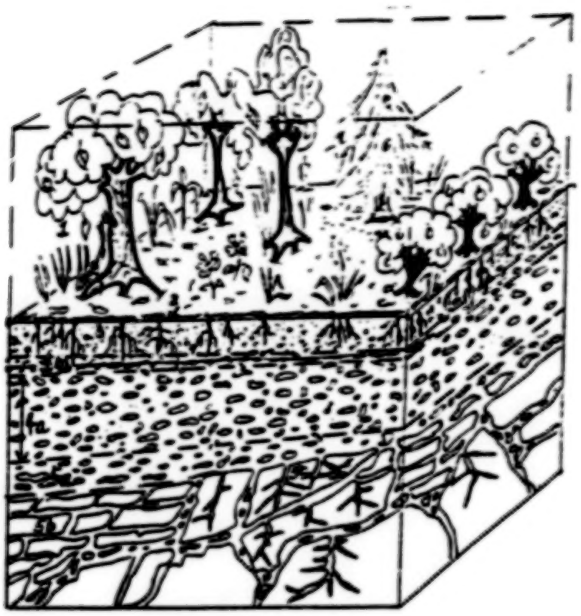


Figure 2. Elemental control volume of porous ground surface; 1-canopy, 2-litter, 3-soil profile, 4a and b-water table rise and fall, 5- substratum rocks

To realistically describe the four ground surface components, the complete soil geography of the land regions of the world must be digitized at a taxonomic or classification level conformal with the spacial scale and sensitivity of the atmospheric model. There is an inverse information trade-off between taxonomic level and ground surface detail. The soil file should not deliver more data than the circulation model can absorb or less than it requires; within this range greater realism enhances experimental results (Dickinson, 1984; Hansen etal, 1985; Rind, 1982). Effective communication between GCM and GIS personnel is essential. Sensitivity testing is important. Given reasonable conformity between taxonomic level and grid cell size, the rectangular volume of a four-component ground surface cell with known X, Y, and Z dimensions may be taken as the elemental control unit of water flow through a porous medium. The equation of hydrologic continuity can be solved by using the governing equation of each component to trace the water flux through the entire porous land surface and to the atmosphere and to the ocean (figures 2,3).

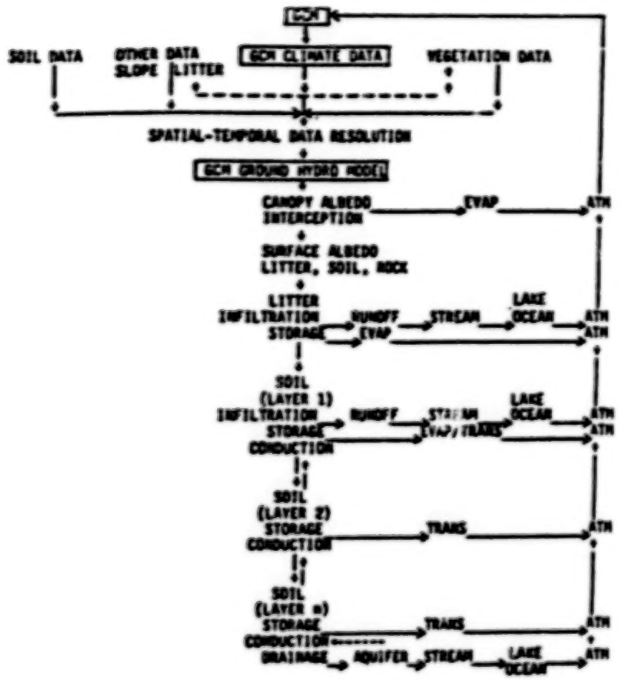


Figure 3. Flow chart of ground hydrology global climate interactive system

This report describes the development, structure, and limitations of a world soil file of 15,413 records obtained from the Soil Map of the World, 1:5,000,000, Food and Agriculture Organization, United Nations, FAO-UN, (1974). Substratum properties may be inferred from the soil profile. When linked to the locationally correspondent Matthews vegetation and land use file (Matthews, 1982), the two files can be coupled to global atmospheric circulation models. The files were prepared for use with the Goddard Institute of Space Studies Global Climate Model, GISS GCM. Data in the files are recorded for $1^{o} \times 1^{o}$ cells; characteristics are numerically aggregated for $8^{o} \times 10^{o}$ and $4^{o} \times 5^{o}$ runs.

3. EXTRACTION OF SOIL DATA FROM SOURCE MAP

Climate models require data on hydraulic soil characteristics that influence climate parameters, characteristics such as, texture, structure, depth, permeability, porosity, minerology. The object of the world soil data file is to identify spacially (horizontally and vertically) and quantitatively, these hydraulic properties. Figures 4 and 5 illustrate some of these features in the field.

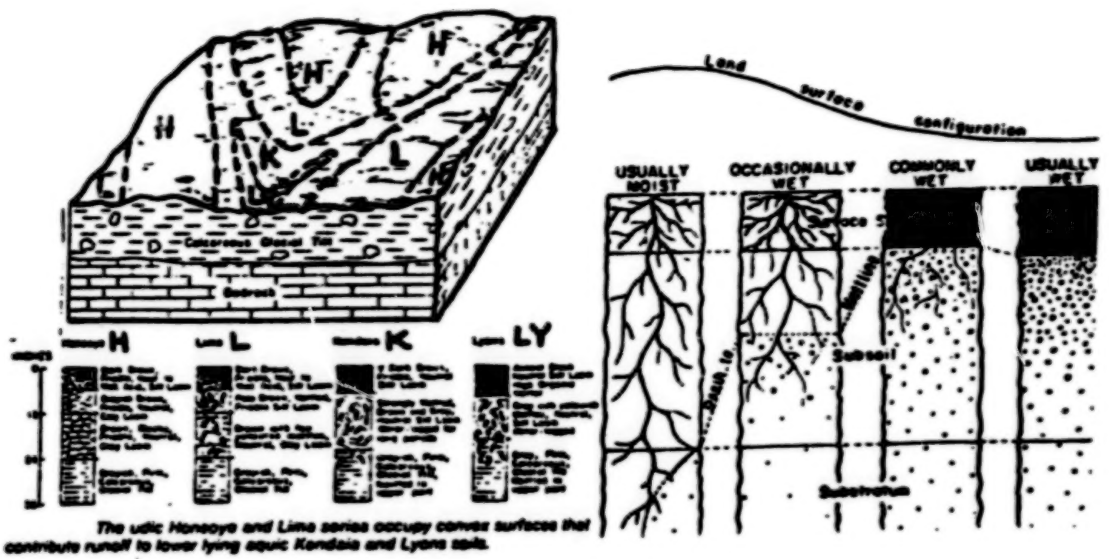


Figure 4. Land surface form and soil hydrology

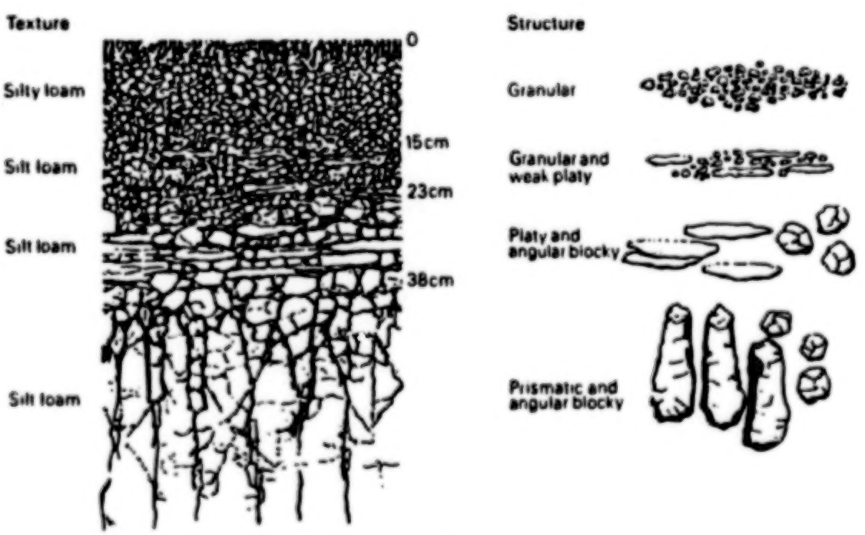
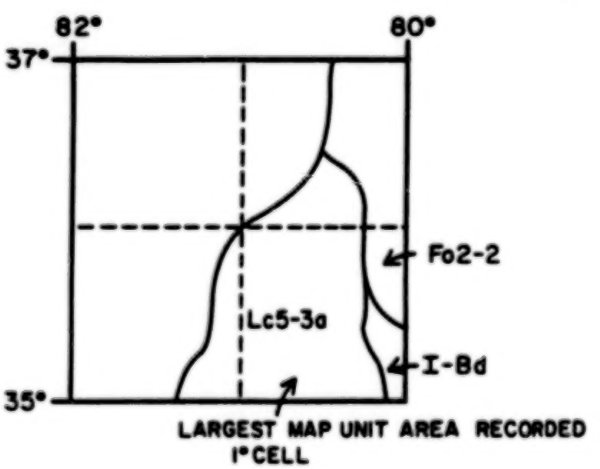


Figure 5. Soil texture and soil structure

3. 1 Data Capture from Source Map

The file data were extracted from FAO Soil Map of the World (1974-1981), scale 1:5,000,000. A set of explicit operating rules was followed. A land cell is defined as a 1^{0} x 1^{o} area occupied by $\geq$ 50 percent land. Land glaciers are included in land cells but inland bodies of water are water cells if water occupies > 50 percent of the cell area. Inland water cells, ocean cells, and sea ice cells are excluded from the file. The land cells conform exactly in type, location, and number to the land cells of Matthews vegetation and land use file (Matthews, 1982).

Each one degree cell is identified by the latitude and longitude of its northwest corner. The source map was published with a two degree grid system over most of its area. Between the 60th parallel and the 80th parallel, the grid lines are four degrees apart, and poleward of the 80th parallel, the interval is eight degrees. One degree cells were obtained by using a transparent overlay to subdivide the published grid. As shown by figure 6, the dash lines delineate the boundaries of the one-degree cell; the northwest corner of the cell of interest is latitude 36^{o} north and longitude 81^{o} west.



Map Unit - Lc5-3a

Soil Association -- Lc5 -- Association of Soils on Landscape
Lc -- Dominant Soil Unit, Chromic Luvisol
5 -- Associated and Included Soil Unit, Chromic Vertisol

Texture Class -- 3 -- Texture Class of Dominant Soil

Slope Class -- a -- Slope Class

Figure 6. FAO Soil Map of the World, 1^{o} grid cell

3. 2 Soil Units and Map Units

On the source map of figure 6, the cell is subdivided into three map units. A map unit bounds an area of common soil units plus slope class. When any one of these three characteristics changes, a new map unit is required. The largest map unit is Lc5-3a. The dominant soil unit in this map unit is Lc, which is Chromic Luvisol. A soil unit is the most basic unit of soils in the FAO classification system. Soil units differ from one another because of their inherent composition. The members of a map unit are a dominant soil unit and associated soil units. The associated soil units are decomposed further according to relative area into associated and (less abundant) included soil units, which occupy smaller areas than the associated soil unit. In this map unit, the other soil unit, indicated by the number 5, refers to Chromic Vertisol; no included soil unit is present. The alphanumeric legend is defined in the FAO Soil Map of the World, volume 1. Thus, the enclosed area of a map unit bounds one or several soil units, forming a natural landscape of dominant, associated, and included soil units that are spacially and pedologically related.

The soil units are arranged in a classification system based on inherent profile properties. The FAO system has two levels. The highest level has 26 members; the lowest level has 106 members or soil units. * Detailed profile descriptions containing information on texture, structure, color, natural soil layers, total depth, layer thickness, and underlying geologic material for the soil units at designated locations are given in the volume accompanying each map. The profile description is representative of the soil unit. The total number ofmap units made up of real world combinations of soil units "occurring within the limits of a mappable physiographic entity as recorded on the source map is estimated to be 5000" (FAO 1974-1981).

The geographic pattern of a soil unit expresses the localized factors of soil genesis. An appreciation of the spacial relationship among soil units and map units is important to the use of the data extracted from the source map and recorded in the file.

*The United States Department of Agriculture, Soil Conservation Service, basic system of soil classification taxonomy has six levels, order, sub-order, great group, subgroup, family, series (SCS-USDA, 1975). The lower level of the FAO classification is approximately equivalent to the great group taxon, but the relation between specific members of the two taxa is not unique.

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As figure 6 shows, a given cell may be occupied by more than one map unit. In that case the one degree cell is characterized by the map unit covering the largest area. For a given map unit the dominant soil unit occupies the largest area of the map unit. The associated soil unit occupies more than 20 percent of the enclosed map unit area but less then the area of the dominant soil unit; the included soil unit occupies less than 20 percent of the enclosed area. The file records the dominant soil unit of the largest map unit; the associated and included soil units are recorded in the file by a numeric code which is referenced on the back of the FAO source map sheets.

The total area of each map unit association on each map sheet is given in the text accompanying the map sheets, but the area of each soil unit is not available. The one degree grid units of the soil file record the associated and included soil units associated with the dominant soil unit, but contain no information on soil unit area. However, FAO has developed an algorithm for estimating the area of each soil unit within a soil association based on the number of soil units in each map unit.

3. 3 Texture Class

Soil texture class is a part of the complete map unit symbol. The textural class of a soil map unit association is for the upper 30 centimeters of the dominant soil. It represents the relative proportions of clay (2 microns), silt (2-50 microns), and sand (50-2000 microns). Three classes are designated: (1) coarse textured - sands, loamy sands, and sandy loams; (2) medium textured - sandy loams, loams, sandy clay loams, silt loams, silts, silty clay loams, and clay loams; (3) fine textured - clays, silty clays, sandy clays, clay loams, and silty clay loams.

The map unit soil association symbol for textural class often shows varying combinations of the three basic classes so that seven textural classes are possible for mineral soils, as (1,2), (1,3), (2,3), (1,2,3) in addition to (1), (2), (3). "Texture class" for organic soils was recorded.

The ambiguity of the textural class designation is evident from the frequent use of multiple legend codes on the source map. FAO interpretation guidelines state that when two textural classes are recorded, each applies to 50 percent of the dominant soil unit. The area guidelines are of limited use to evaluate water flux at climate modeling resolution. Also, for dominant soils of mapping units whose textures are not given for the map unit, FAO pre-

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scribes medium textured. These FAO rules are used for the 106 soil units, except for 10 soil units which default to coarse, and for 7 soil units which default to fine. Because the FAO rules are too cumbersome to apply to atmosphere modeling, the file records of soil texture for multiple textural classes were obtained from the soil texture triangle after averaging multiple values. File records for areas with no texture class given were derived from adjacent soil unit texture classes and regional geology.

3. 4 Slope Classes

Three basic classes are used to describe the surface slope of the area of a soil map unit association. They are (1) 0-8 percent, level to gently undulating, (2) 8-30 percent, rolling to hilly, (3) 30 percent, steeply dissected to mountainous. The soil map unit association legend often describes the slope as combinations of the basic slopes, so that seven possible categories exist, (1,2), (1,3), (2,3), (1,2,3), and (1), (2), (3). Multiple class slopes were determined from the averages of the basic slope classes and entered into the file.

Slope evaluations are treated on the FAO source map similar to textural classes. FAO interpretation guidelines state that the slope class applies to the dominant soil of the map unit; if two or more classes are indicated each occupies an equal area of the dominant soil unit. Where slope is not described for a dominant soil unit, slope classes are allocated according to the 26 major categories of soil units; some of the allocations include two slope classes. Slope classes also apply to associated and included soil units. For missing slope classes the data file class was derived from geomorphic evidence and adjacent map unit designations.

3. 5 Soil Phases and Miscellaneous Land Units

Additional ground surface information of climatic interest is provided by the FAO map as overprints apart from the soil map unit association. These are phases and miscellaneous land units. Phases are subdivisions of soil units which have not been systematically recorded and, hence, are not diagnostic for the separation of soil units. Nevertheless, phases provide hydraulic data important for climate modeling, as, stoniness, permafrost, salinity, water table, and hardpans or hardrock within 100 centimeters of the surface. Generalized ground surface properties also are given as overprints for miscellaneous land units, as dunes or shifting sands, glaciers, salt flats, rock debris, and flooding or ponding. These areas are represented with and without map association. Where necessary,

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soil units with analogous physical properties are assigned and the extrapolation recorded in the file.

4. FILE STRUCTURE, USE, OUTPUT EXAMPLES

The object of the file is to record the values of a selected set of geocoded soil parameters important for climate modeling. File data provide the basis of the spacial configuration of ground surface hydrologic and energy properties applicable to a global climate model. The user sets up the classification system according to his research needs and model perceptions. File data are then available to prescribe the physical equations governing water-energy-ground surface-atmosphere interactions according to a numeric scheme. The file can be updated as empirical information on soil behavior and field distributions of soil types are improved.

To obtain information from the file, the user addresses the area of interest by referencing the appropriate coordinates. Some of the physical data are directly available, as texture and slope classes. Other data on the soil profile, substrata, and or phase and miscellaneous land units are obtained by decoding the dominant, associated, and included soil units, and the land unit and phase files. It is necessary to reference a dictionary of climatic ground surface hydrology parameters derived from soil profile descriptions of the 106 soil units, and the phase and miscellaneous land units given by the FAO report. A user can create or adapt a dictionary for special research needs and numeric GCM requirements stipulated by governing physical equations. The format of the file and descriptions of selected $1^{o} \times 1^{o}$ grid cell area are given by table 1. Cartographic and tabular output can be obtained of bounded areas for designated ground hydrologic attributes as illustrated by figure 7 and tables 2 and 3.

5. DISCUSSION

The world soil file is a raw data file, a file of soils classified for GCM use. Groups of soils can be obtained from the file by defining value class intervals for parameters. To model the role of soils in climate change, the properties of soil horizons are extrapolated from specific representative site profile descriptions of the 106 soil units. These data are fitted to basic physical equations that are coupled to a numeric scheme in order to evaluate the sensitivity of soil properties for climate modeling. The world soil file provides the raw data in a form that facilitates

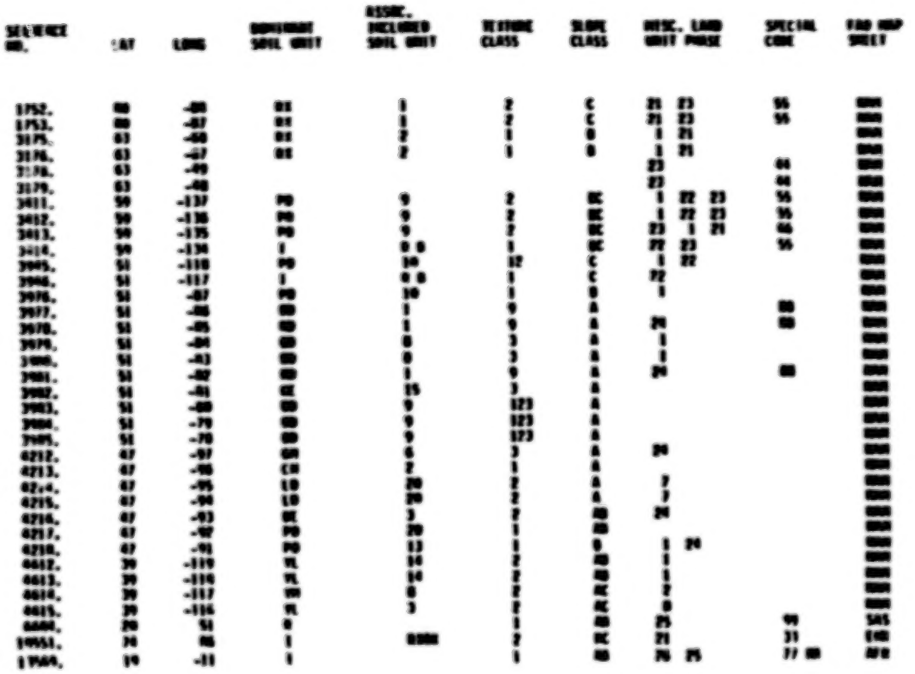


Table 1-a Format of soil file

user ground surface model experimentation with an atmosphere general circulation model, or with meteorological data as the forcing function.

Experience with the preparation of the file revealed several principles applicable to the structuring of geographic information systems. Two other global soil files did not explicitly consider these organizational principles (Lin et al, 1979; Wilson et al, 1985). The principles are: (1) the design of the GIS should be coordinated with model processing sensitivity and spacial resolution of the analytical system to which it is coupled (2) field capture of raw data for direct entry into a GIS file should be carried out in a manner that reflects population structure, or, for a sample, should be sensitive to sample size and distribution; sensitivity considerations should also involve instrument accuracy (human or mechanical), observation frequency (if relevant), data homogeneity and representiveness, and the size of the spacial cell used to aggregate observations; the World Soil Map source has several levels of field reliability (Gardner, 1982); the time interval to aquire the raw data is not given in the FAO report; a reasonable "guesstimate" would be 20 years, during which period concepts of soil classification undoubtedly changed; the process of

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Sequence No.	Description
1753	Lat. 80N, Long 87W; dominant soil unit -- Gelic Regosol; associated and included soil unit -- none; texture class -- medium; slope class -- steeply dissected to mountainous; phase and misc. land unit -- permafrost, glacial; special code -- soil on FAO map, glacier on Matthews vegetation file; FAO map sheet -- North America
3176	Lat. 63N, Long. 67W; dominant soil unit -- Gelic Regosol; associated and included soil units -- lithosol and gelic gleysol; texture class -- coarse; slope class -- rolling to hilly; phase and misc. land unit -- stony phase and permafrost; special code -- Map and Matthews vegetation file agree; FAO map sheet -- North America
3179	Lat. 63N, Long. 48W; no soil unit present; texture class and slope class not given; phase and misc. land unit -- glacier; special code -- cell not on FAO map, cell in Matthews vegetation file is glacial; FAO map sheet -- North America
3413	Lat. 59N, Long. 135W; dominant soil unit -- Orthic Podzol; associated and included soils -- histosol, vitric andosol; texture class -- medium; slope class -- rolling to hilly and steeply dissected to mountainous; phase and misc. land unit -- stony, glacial, permafrost; special code -- glacial on FAO Map but soil in Matthews vegetation file; FAO map sheet -- North America
3945	Lat. 51N, Long. 119W; dominant soil unit -- Orthic Podzol; associated and included soil units -- Lithosol; texture class; coarse and medium; slope class -- steeply dissected to mountainous; phase and misc. land unit -- stony and intermittent permafrost; special code -- none; FAO map sheet -- North America

Table 1-b Format of file listing

homogenizing the soils of many national systems of classification required 10-15 years;(3) if a GIS file is derived from an existing tabulation or source map the problems of point 2 above are exacerbated by the two level data capture method.

Compilation of the initial data in map or tabular form and the method used to extract the data from the primary or secondary source affects its utility. These presented serious problems in the compliation of the World Soil File: (a) phases and miscellaneous land units are not bounded clearly (b) phase, land unit, and substratum data were inferred from verbal descriptions and ancillary information on geology, geomorphology, vegetation, and drainage conditions, where necessary (c) the high taxonomic level of the soil unit in the FAO classification system made it necessary to rely on site specific soil profile descriptions located at great distances from grid cells (d) difficulties of using a high taxonomic soil unit level were enhanced by the designation of the map unit to encompass three categories of soil units, dominant, associated, and included soil units, in a single divided area.

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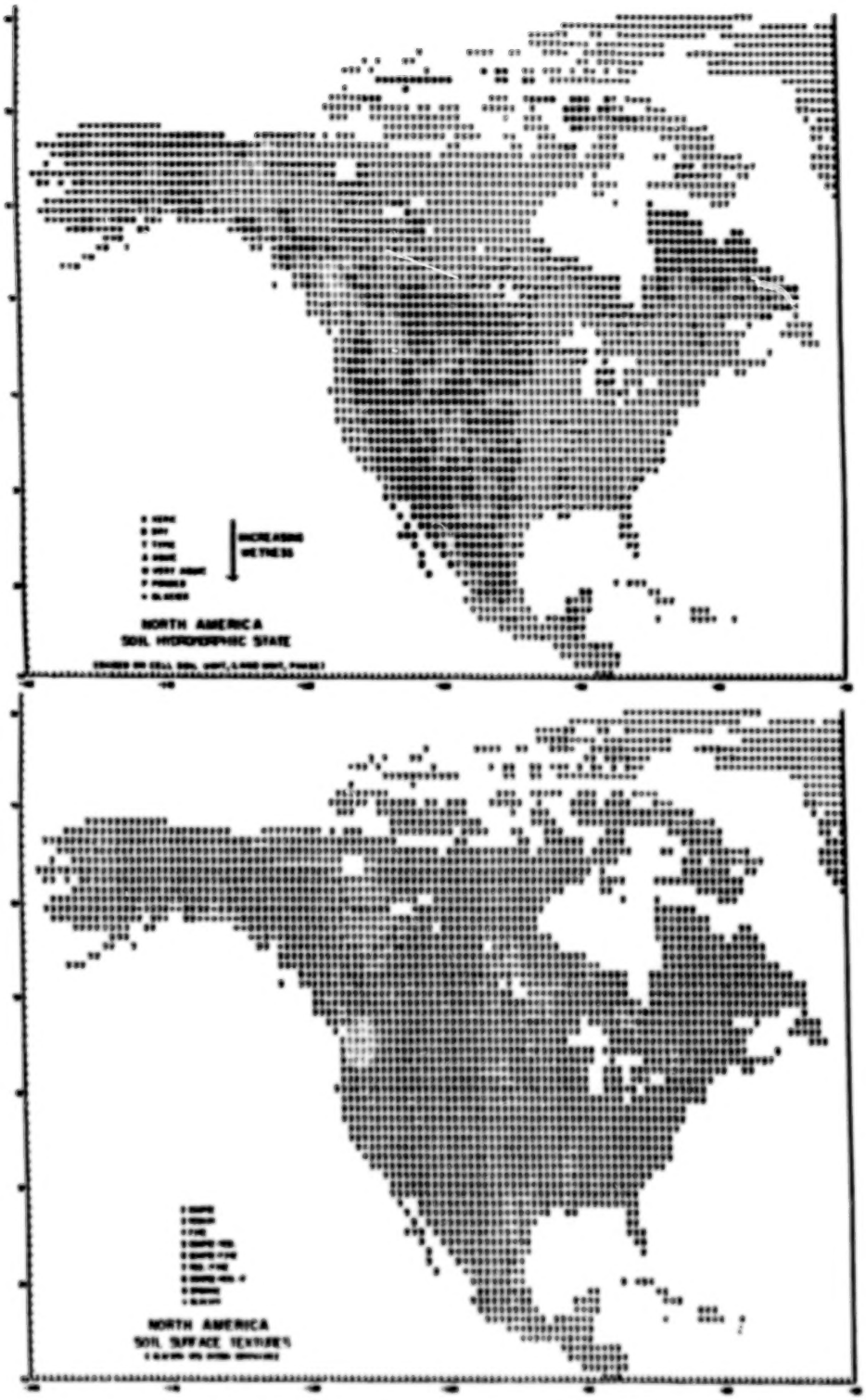


Figure 7. Soil texture classes (lower) and moisture states (upper) for North America; each character represents a one degree grid cell

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MID-LAT. COORDS.	1 CELL AREA (*10**5KM)	NO. SOIL CELLS	AREA SOIL (*10**5KM)	NO. ICE CELLS	AREA ICE (*10**5KM)	NO. WATER CELLS	AREA WATER (*10**5KM)
20.5	11.501	118.	1366.584	0.	0.000	242.	2892.656
21.5	11.504	121.	1391.968	0.	0.000	239.	2749.429
22.5	11.473	133.	1519.265	0.	0.000	227.	2593.031
23.5	11.139	130.	1519.968	0.	0.000	226.	2562.688
24.5	11.251	131.	1473.870	0.	0.000	229.	2546.673
25.5	11.160	142.	1584.687	0.	0.000	218.	2432.829
26.5	11.065	141.	1560.105	0.	0.000	219.	2423.265
27.5	10.967	199.	1630.109	0.	0.000	211.	2314.879
28.5	10.866	199.	1619.016	0.	0.000	211.	2292.388
29.5	10.761	154.	1657.231	0.	0.000	208.	2236.885
	10 DEGREE TOTAL:	1372.	15325.309	0.	0.000	2228.	24963.953

Table 2. Surface properties of a 10° latitude band, 20° - 30° N

These remarks should not detract from the achievement of the FAO Map of the Soils of the World. The source map was not designed to be used to characterize the ground hydrology of the earth with the precision that GCM's, based on physical principles, require. In attempting to adapt GIS to GCM several basic issues were confronted which are common to the organization of all geographic information systems. There is more to the emerging GIS science than the encyclopedic storage of data in geographic boxes. Awareness of GIS principles facilitates the structuring of new spacial data systems or adaptation of existing primitive ones, to new purposes, as the use of the FAO Soil Map as a source map to interactively couple a ground hydrology model to a model of the atmosphere circulation system.

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[illegible], ORTHIC ACRISOL

(AO occupies 137 1° cells in land with an area of 152[illegible] km^2 which is 9.97% of the total land soil area and is 25.52% of the AO soil unit area in the world and is 3.03% of the total soil area of the world)

ICE	COARSE	MEDIUM	
0.000	0.000	200.022	AREA OF CELLS, (*) KM^2
0.000	0.000	13.142	TEXT CLASS AS PERCENT OF THIS SU IN 10° BAND
0.000	0.000	3.405	TEXT CLASS AS PERCENT OF THIS SU IN WORLD
0.000	0.000	5.498	TEXT CLASS AS PERCENT OF ALL SAME TEXT IN 10° BAND
0.000	0.000	0.367	TEXT CLASS AS PERCENT OF ALL SAME TEXT IN WORLD
0.000	0.000	1.350	TEXT CLASS AS PERCENT OF ALL ALL SU IN 10° BAND
0.000	0.000	0.135	TEXT CLASS AS PERCENT OF ALL ALL SU IN WORLD
0.000	0.000	10.076	TEXT CLASS AS PERCENT OF ALL SAME TEXT, SAME SU IN WORLD

FINE	C-M	C-F
804.201	0.000	0.000	AREA OF CELLS, (*) KM^2
52.629	0.000	0.000	TEXT CLASS AS PERCENT OF THIS SU IN 10° BAND
13.996	0.000	0.000	TEXT CLASS AS PERCENT OF THIS SU IN WORLD
30.961	0.000	0.000	TEXT CLASS AS PERCENT OF ALL SAME TEXT IN 10° BAND
3.770	0.000	0.000	TEXT CLASS AS PERCENT OF ALL SAME TEXT IN WORLD
5.247	0.000	0.000	TEXT CLASS AS PERCENT OF ALL ALL SU IN 10° BAND
0.541	0.000	0.000	TEXT CLASS AS PERCENT OF ALL ALL SU IN WORLD
56.117	0.000	0.000	TEXT CLASS AS PERCENT OF ALL SAME TEXT, SAME SU IN WORLD

M-F	C-M-F	ORGANIC
523.040	0.000	0.000	AREA OF CELLS, (*) KM^2
34.229	0.000	0.000	TEXT CLASS AS PERCENT OF THIS SU IN 10° BAND
9.095	0.000	0.000	TEXT CLASS AS PERCENT OF THIS SU IN WORLD
50.584	0.000	0.000	TEXT CLASS AS PERCENT OF ALL SAME TEXT IN 10° BAND
5.201	0.000	0.000	TEXT CLASS AS PERCENT OF ALL SAME TEXT IN WORLD
3.413	0.000	0.000	TEXT CLASS AS PERCENT OF ALL ALL SU IN 10° BAND

C-M, coarse medium; C-F, coarse fine; M-F, medium fine; C-M-F, coarse medium fine; SU, soil unit; TEXT, texture (see text for explanation)

Table 3. Texture classes and global percent of a soil unit

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A tape and documentation of the World Soil File are available on request to NCAR, Data Support Section, P.O. Box 3000, Boulder, CO 80307

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SMALL-SCALE SOIL MAPS IN THE UNITED STATES AS PROTOTYPES FOR HANDLING SOILS IN A GLOBAL GEOGRAPHIC INFORMATION SYSTEM

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ABSTRACT

The United States Soil Conservation Service is developing a nationwide set of soil maps at a scale of 1:250,000. The U.S. Geological Survey is cooperating to demonstrate how the soils data can be used in a geographic information system (GIS).

The small-scale soil maps may be suitable as prototypes for handling soils data in a global data base. The soils are mapped in groups of associated soils. Each mapping unit is described in terms of a more detailed set of soil phases that are not delineated as soil polygons. Thus, there is more detail in the attribute data than in the graphic data. In this way, the graphics can be mapped at a small scale, while retaining quantitative information on the detailed composition of the mapping units.

Small-scale soil maps are made by generalizing more detailed soil survey maps where available. Where more detailed maps are not available, a GIS can be used to analyze available geologic, topographic, vegetative, and climatic data and extrapolate soils data from analogous areas.

The experience gained in analyzing soils data in conjunction with other natural resource data in the United States can guide similar efforts for other parts of the globe. Research on using soils in a global GIS should address efficient data management and intelligent systems for choosing appropriate source data based on data quality.

1/ Work performed under U.S. Geological Survey contract 14-08-0001-22521.

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1. RESOLUTION OF DATA

Global studies are undertaken to understand relationships among environmental processes at continental scales, to improve our capability to provide life support for people, and to help protect our environment from long-term degradation. Knowledge of the world's soils is important for all of these endeavors.

In considering what soil information is needed at a global scale, we need to define three different resolution dimensions: space, time, and information. Spatial resolution is typically defined in terms of the scale of the map on which the information is portrayed. Temporal resolution is defined in terms of how often the map is updated. Informational resolution relates to the amount of detail and secondary interpretations that are available to define the mapping units.

Typically, global soil maps have had low resolution in all three of these dimensions. They are at scales of 1:5,000,000 or smaller, they are updated at time intervals measured in decades, and they have less than several hundred distinct mapping units and interpretations. An example of a global soil map is the Food and Agriculture Organization (FAO) Soil Map of the World (5).

At the other extreme, soil maps for agricultural planning may be at a scale of 1:10,000. In areas where irrigation or drainage research is conducted or where land-changing modifications are introduced, annual maps may be appropriate. While a published map for a county may have several hundred mapping categories, a set of equivalent maps covering the globe would have several hundred thousand categories. Baumgardner and others (1) discuss the relationships between soil surveys at different scales in a global context.

Temporal resolution has been a minor issue for soil mapping. Soils are generally considered to change more slowly than many other resources that are observed and mapped. Frequent updates are usually not needed to reflect changes in the soil itself. Updates to soil maps are required when we change the way we think about and classify soils, or in order to adjust to new uses and technical advances in management. The temporal resolution of maps becomes more significant if land use is assessed in conjunction with soils. In measuring changes during a growing season, weekly maps of vegetation condition may be desirable and achievable.

The informational dimension is characterized by the amount of detail available in the attribute data. In the United States, the Soil Conservation Service maintains computerized files on all of the soil series used in the country. The data base is called the Soil Interpretations Record, and it contains approximately 150 soil properties and interpretations for approximately 16,000 soil series. A partial list of the soil properties and interpretations is given in Table 1.

Table 1. A partial list of the properties and interpretations in the Soil Interpretations Record data base, maintained by the Soil Conservation Service for each soil series in the United States.

Soil Interpretations Record number
Component name
Component percentage
Slope
Soil classification
(order, suborder...)
Corrosivity (steel, concrete)
Flooding (frequency, duration)
Flooding dates (beginning, end)
Water table (depth, kind, dates)
Cemented pan (depth, hardness)
Bedrock (depth, hardness)
Subsidence (initial, total)
Hydrologic group (runoff)
Frost action
Capability and yield, by crop
Woodland suitability
(species, site index)
Windbreak suitability
(species, height)
Wildlife habitat suitability
Potential native plant community
Rangeland (yield, composition)
Woodland understory

Layers (up to 6 layers)
Depth
Texture
Sieve percentages
Liquid limit
Plasticity index
Clay percentage
Bulk density
Permeability
Available water capacity
pH
Salinity
Shrink-swell
K Factor (erosion)
T Factor (erosion)
Organic matter

Use interpretations
Septic tank absorption fields
Sewage lagoons
Sanitary landfills (trench, area)
Dwellings
Small commercial buildings
Local streets and roads
Resources (sand, gravel, topsoil)
Ponds, drainage, irrigation
Recreation (camp, picnic, and playground areas; trails)

To better manage our natural resources, we must increase the amount of detail in each of the spatial, temporal, and informational dimensions. If we are to better understand and attempt to manage the global environmental system, we must have a model of how the system operates. In prior decades, studies that integrated natural resource information with social and economic factors were limited to manual methods of processing geographic interrelationships (2). We now have automated tools to process and interpret the studies.

2. GOALS FOR ORGANIZING GLOBAL DATA

We cannot afford to build real-time geographic information systems (GIS) for all natural resources and related human interactions for the entire globe. We must be selective in what information we include, how it is interrelated, how often it is updated, and the ways in which it is queried.

To design global information systems, we need to know how they will be used. We make maps of natural resources so that we can better manage and use those resources. Some of this management must take place at the policy level, in terms of national policies for resource use, international trade, and economic development. The policy makers need summary data, in which relationships and trends are highlighted. In order for policies to be implemented in terms of changes in natural resource use, however, the policies ultimately need to be made specific for individual parcels of land.

Many resource inventories in the past either have been made for the management of localized areas for limited purposes, or have been highly generalized for policy-making purposes. Geographic information systems technology is beginning to provide us capabilities to build integrated systems that are suitable for both the management and the policy-making efforts. Within the next decade, we can expect additional automated procedures for map generalization. This will enable us to maintain detailed spatial data bases at the level needed for operational management, yet quickly aggregate and generalize the data in a form useful for policymakers.

3. SOIL DATA IN A SOCIAL CONTEXT

For natural resource planning, the soil layer represents an appropriate stratification for many agricultural, rangeland, and forestry interpretations. These interpretations, in turn, may become a basis for interpreting economic and social factors. We must account for a variety of land uses that are possible on each type of soil. There are various levels of technological inputs that people can use to increase the intensity with which they manage the land. For agricultural land management, these technological inputs include irrigation, fertilization, mechanization, education, research, and financing. All of these have costs and benefits, they require management at a policy-making level, and they have different demands for information about the basic natural resources.

A policymaker may need a map showing the diffusion of a new technology into an area; for example, a new type of irrigation system. It would also be desirable to have a map showing the soils that are appropriate for the technology. For a policymaker, the

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issue would be whether or not there are sufficient appropriate soils in an area to make an investment in the technology worthwhile. For the agricultural extension agent and the farmer, the knowledge would need to be more specific in terms of which fields to use for testing the technology.

As we try to meet the goal of improved spatial, temporal, and informational resolution, we may find that our choices about resolution represent quantum jumps, rather than a smooth continuum. By carefully connecting data from different sources, each adapted to precision in the spatial, temporal, or attribute domains, we can create more useful data bases than if we focus on only one domain.

4. THE STATSGO SOIL MAPS

A project is underway that combines detailed attribute data with generalized spatial data. The resulting digital maps and attribute data are called the State Soil Geographic (STATSGO) Data Base. These data will provide small-scale soil maps, at a reasonable cost and in a reasonable timeframe, for the entire United States (excluding Alaska). By linking these maps to a complete set of attributes that were developed for mapping at greater detail, it is possible to capture a much larger amount of information for the general maps than otherwise would be possible. There is some loss in information, but it is less than the loss that would be expected for a generalization from 1:20,000 scale to 1:250,000 scale.

The generalized map units for the 1:250,000-scale maps are linked to detailed soil-phase information commonly used in mapping at scales of 1:20,000 and larger. The percentage composition of the detailed soil-phase units that occur within each of the generalized mapping units is recorded in the data base. Table 2 shows a portion of a table generated from the data base that relates the general mapping units to the detailed components using the percentage composition. Figure 1 shows an interpretive STATSGO map for available water capacity (inches of water available to plants per inch of soil depth). Although more data are available to produce interpretive maps, not all of the data for a property can be expressed in the same map. A series of maps is needed to portray all of the data for any given attribute. Interpretive maps can be made for any of the attributes shown in Table 1.

5. SMALL-SCALE SOIL MAPPING IN OTHER COUNTRIES

Maps similar to the STATSGO maps can be produced in other parts of the world. Where detailed soil maps are available, the general maps

Table 2. A portion of the tables for STATSGO soil attributes.

Component table

Map unit identifier1/	Component number	Component percentage	SIRNO2/	Depth to Seasonal High Water Table3/ (low)	(high)
VA038	1	65	SC0022	-3.0	0.0
VA038	2	15	VA0199	0.0	0.5
VA038	3	12	NC0044	0.0	1.0
VA038	4	2	AL0033	0.5	1.5
VA038	5	4	VA0145	1.5	2.5
VA038	6	2	VA0032	6.0	6.0

1/ Relates to a polygon on the general soil map; several components are illustrated for map unit VA038, with the percentage composition of the component within the map unit being recorded in the table.

2/ Soil Interpretations Record number; links the component to the detailed attribute information, as summarized in Table 1.

3/ A negative number indicates standing water during the wet season.

can be made by generalizing the detailed soil maps. This method is being used for much of the STATSGO map production (3). The appropriate general soil units are drawn on a copy of the detailed map and transferred to a base map at the scale of the general map. The percentage composition can be determined manually by making line transects across the detailed map. The detailed mapping units are recorded in a form that allows the attributes to be extracted from the Soil Interpretations Record data base.

Where detailed maps are not available, a GIS can be used to analyze related natural resource information that is available, such as geologic, topographic, vegetative, and climatic data. The related data can be digitized, and a GIS can be used to overlay the factors. If the composite map of related factors is reasonable, it can be used as a pre-map for reconnaissance soil mapping. The properties and interpretations from soils in a mapped area that have similar geologic, topographic, climatic, and vegetative conditions can be extrapolated and assigned to the mapping units of the pre-map.

The extrapolation process depends on a consistent system for classifying soils. A recommended method uses the soil taxonomy defined by the United States Department of Agriculture (4). This taxonomy uses a hierarchical system to classify soils. At the

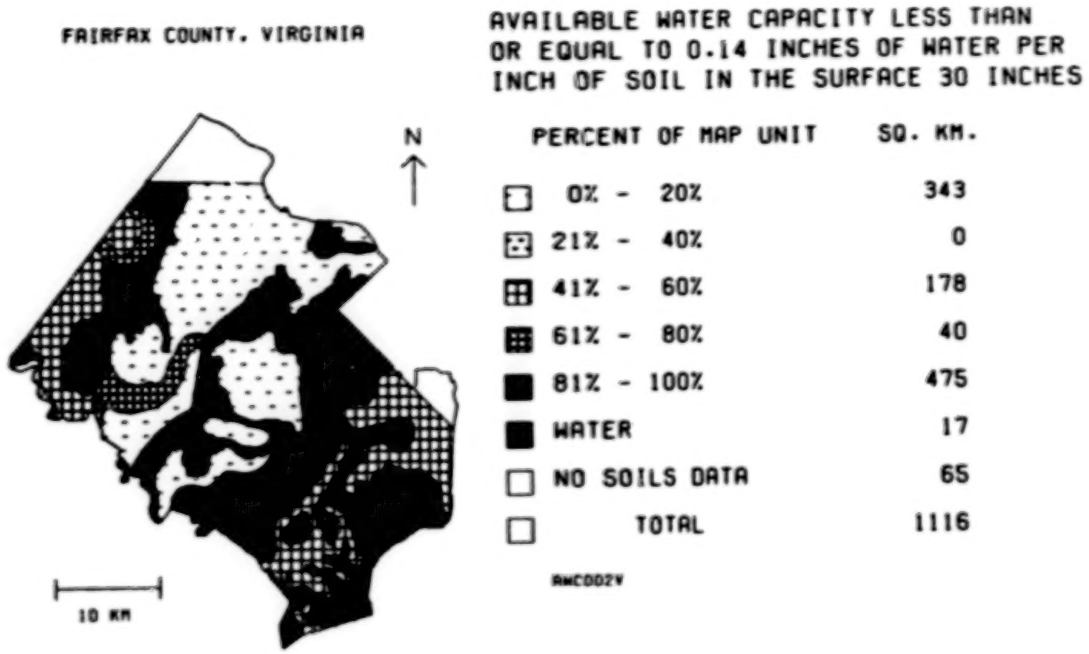


Figure 1. An interpretive STATSGO map portrays the average available water capacity, weighted by the thickness of each soil horizon layer, with calculations limited to the surface 30 inches of the soil. Each STATSGO map unit delineation (polygon) is classified into one of the five ranges of percentages, based on the percentage of the mapping unit having components with an available water capacity less than or equal to 0.14 inches of water per inch of soil.

highest level are the the orders, then the suborders. These, in turn, contain the great groups, and so on to the level of soil series.

The Soil Interpretations Record data base, maintained by the Soil Conservation Service, is a possible source for soil characteristics for analogous soils used in this extrapolation. The attributes for areas that have already been mapped can be extracted from these data according to the soil series. These properties can then be attached to the analogous soils in the area for which the new map is being constructed. It may be desirable to extrapolate in the form of percentage composition of a set of components, following the pattern of the STATSGO data shown in Table 2. The pre-map produced in this way can then be corrected and refined in the field investigation phase of the soil mapping process.

6. THE RESEARCH AGENDA

Two areas of research on using soils in a global GIS that may prove fruitful in the next decade are efficient data management and using intelligent systems for choosing appropriate source data based on data quality.

6.1 Efficient Data Management

Research is needed on efficient data management for very large geographic data bases. The arc-node data structure has been found to be superior to a polygon data structure for vector data. The debate on whether vector or raster data structures will ultimately prevail has resolved into an understanding that both are useful, and that we can convert data between them. Within the next decade, we can look for progress in both hardware and software that will improve our capabilities to quickly process geographic data. The challenge for us is to clearly define the types of data management requirements that we have.

One area for research is the data generalization process. We should be able to automatically handle the generalization from detailed maps to summary maps. This research will help to bridge the gap between operational managers at the field level and policymakers at administrative and legislative levels.

Computer hardware and software investigations will continue on how to store and extract geographic information. The geographic information can typically be described on a continuum from zero to three spatial dimensions in terms of points, lines, areas, or volumes. Capabilities should continue to be developed so that we can project and generalize from the higher dimensional spaces to lower dimensional spaces (such as from areas into lines). Conversely, we should be able to create extrapolations of influence, often called buffer zones, from the lower to the higher dimensional spaces (such as from lines into areas).

We can also improve the human interfaces for handling complex spatial objects. The existing GIS technology can handle objects represented as points, lines, or polygons. Complex objects can be considered as a collection of these basic elements, as in the cartographic representation of an airport. The polygons that result from the overlay of general soils and land use may have attributes for both layers represented in terms of percentage composition. These are complex objects in the informational domain, and the next generation of software should provide tools to display and manipulate such objects.

6.2 Intelligent Systems for Map Overlay

A second area of potential research would be to develop intelligent systems to account for differences in thematic content, data quality and completeness, and map scale in the map overlay process. The availability of the overlay technique is one of the most powerful tools available in a GIS. But it is also subject to abuse by inexperienced users. One of the goals of research in artificial intelligence is to capture the experience and procedures of experts and to make them available to novices.

Overlay processing can create new information from the intersection of several maps. The judgment as to whether this new information is valid or spurious rests with trained analysts. The training process for analysts could be speeded up if we were able to provide a decision structure for how the experts make the necessary choices. With developments in the field of artificial intelligence, and with additional experience gained in the processing of natural resource data, there seems to be a confluence of two fields of research that may prove mutually beneficial.

An expert takes map accuracy into account in making a map overlay. The judgment of whether an overlay will improve the accuracy of an interpretation depends on the quality of the input maps. Research is needed to understand how to express the accuracy of a map. One approach may be to couple with each thematic map a set of additional maps describing the spatial, temporal, and informational accuracy of the thematic map. It is overly simplistic to say that when inaccurate maps are combined together, that the result must be less accurate than any of the sources. It is possible for the best information in each to be selected, and to produce a map that is more accurate, for a particular interpretation than the input maps taken separately. The assessment of accuracy is not simple because the input maps may need to be combined in a different way for each possible interpretation. Thus, it is not possible to define in advance the accuracy of an overlay map, until the purpose of the analysis is defined and the relevance of the errors to that purpose are determined.

In a human context, some judgment is needed concerning the consequence of errors in the map. If the purpose of the map is to locate sites that may be beneficial (resource extraction or facility location), the consequences of missing a potential location may be minor if other locations are available. However, if the purpose of the map is hazard avoidance (avoid city parks on former toxic waste dumps), the consequences of misclassifying a location may be severe. Even the economic perspective of the population using the map may be important. Famine-prone farmers may use a risk avoidance strategy rather than an economic maximizing strategy. They may produce a crop with a minimal yield if that yield is likely to be achieved, rather than aim for a higher yield with the risk of a greater chance

of crop failure. In that situation, a map showing the crops that would maximize yield would be in error with respect to the human purpose for using that map.

7. CONCLUSIONS

Geographic information systems have numerous applications in resource inventory and monitoring. A GIS is a data management tool that provides for automated handling of geographic data with capabilities to input, store, update, query, and display. It is an integration tool that can be used to combine disparate data collected from different sources. An example of this integration capability is the extrapolation from the properties and interpretations contained in a data base for soil series in the United States to areas of similar topographic and climatic characteristics in other parts of the world. A GIS is also an analysis tool, allowing us to evaluate spatial relationships.

GIS technology encourages the sharing of data in interdisciplinary natural resource studies. The more information we have, the better we can collect the next increment of information. A synergism exists between remote sensing and field data collection, in that using both together provides more useful information than using either independently.

Upcoming developments in GIS technology will involve improving the linkages between analysis and decision making. We will learn more about the information requirements for making decisions, and we will formalize the processes by which we combine maps of varying quality and accuracy to form interpretations. If we can quantify the information needs for decision making, then we can begin to quantify the value of that information.

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EDUCATION

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USMGIS: AN ENTRY LEVEL SYSTEM

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ABSTRACT

USMGIS is a basic raster-oriented geographic information system developed to provide initial student exposure and meet basic local requirements for geographic information system technology on standard microcomputer hardware. USMGIS introduces students to most of the basic functions of geographic information systems and performs the tasks most often needed by users who deal with small geographic areas. It is programmed entirely in Ada*, which improves portability and also provides great flexibility in array sizes, eliminating one of the traditional problems of raster oriented systems.

1. INTRODUCTION

Geographic information systems, under other names, have long been a basic tool of the branch of geographic research known as area analysis. Recently such systems have become a major tool of geographic applications as well as geographic research (Tomlinson et al., 1976; Monmonier, 1985). Most currently available geographic information systems are large, expensive computer programs which require either large or highly specialized computer hardware systems (cf. Opitz, 1986).

These systems generally do not meet the needs of either educational institutions or most potential GIS users. For example, a recent graduate of the University of Southern Mississippi Urban and Regional Planning Program is employed by a nearby county government which told him to buy whatever computer hardware and software he needed, so long as it did not cost more than $10,000 and, preferably not more than $5,000. In order for a geographic information system to be used in that county, that GIS must consist of economically priced software which requires nothing extraordinary by way of hardware. Faculty members of most educational institutions are faced with similar or even more severe budgetary constraints.

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* Ada is a registered trademark of the U.S. Government, Ada Joint Programs Office.

These constraints deny many potential students and applications users reasonable access to geographic information system functions. USMGIS, the geographic information system developed at the University of Southern Mississippi Cartography Laboratory, specifically to meet these two needs, initial student exposure to geographic information systems and local GIS applications requirements, while operating on the same microcomputer hardware which will support standard word processing, spreadsheet, and data base programs.

2. CHARACTERISTICS OF USMGIS

Development of USMGIS to fulfill the needs and hardware limitations specified above led the authors to four early design decisions. First, output should be oriented to dot matrix printers rather than to video screens. This decision was based on the fact that commonly used video screens vary widely in resolution, generally lack square graphics formats, and are completely non-standard in their graphics commands. Second, the system should focus on raster-based processing. While raster processing has some shortcomings from a cartographic standpoint, it is generally more efficient and is more easily compatible with dot matrix printers. Third, the system should accept vector vector data as well as raster input. Vector data is widely available and may be readily produced with any digitizer so even a raster-based processing system should accept such data and provide a rasterizing function. Fourth, the system should operate through a series of simple menus supported by help screens since this is the program operation form most familiar to microcomputer users.

The principal data manipulation functions of USMGIS are construction, comparison, and summarization of maps (Figure 1). Construction capabilities allow the user to employ vector data to develop rasterform choropleth, dasymetric, contour, trend surface, and residual maps. That is, the system is capable of developing all standard thematic map products by common cartographic methods (Robinson et al., 1984; Davis, 1986).

Figure 2 illustrates the activities included in the continuous surface mapping option ofthe menu. The contour and trend surface programs are actually included as packages directly accessed at this point. The residual mapping function transfers the user to the map comparison package which could also have been accessed directly from the main menu. Map comparison capabilities focus on using preexisting raster files, such as digitized images or maps, or raster files created by the system's map construction capability. A sieving or filtering

Figure 1. USMGIS main menu general help screen, indicating the classes of activities which may be performed.

TYPES OF ACTIVITY INCLUDED IN EACH OPTION

1. Vector map data processing.
   Converts arc to polygon or to raster data.
2. Vector map analysis.
   Performs relationship tests on vector data, provides numeric data classification procedures, and performs selected statistical tests on the data.
3. Vector database analysis.
   Provides relational database operations for data records associated with vector map files.
4. Grid map analysis.
   Performs tests of relationships between map arrays, provides quantitative and qualitative classification procedures for map arrays, and performs selected statistical tests on the data.
5. Grid-based discrete surface mapping.
   Produces choropleth and dasymetric maps.
6. Grid-based continuous surface mapping.
   Produces contour and trend surface maps.
7. Terminate this session.

Figure 2. USMGIS, continuous surface mapping menu general help screen, indicating types of activities available in this option.

TYPES OF ACTIVITY INCLUDED IN EACH OPTION

1. Construct a contour map.
   Uses a data file of coordinate pairs and associated quantitative values to produce a contour map.
2. Construct a trend surface map.
   Uses a data file of coordinate pairs and associated quantitative values to produce a trend surface map.
3. Compare two maps.
   Uses map files produced by either the contour or trend surface procedures to produce residual, ratio, or difference maps.
4. Print a map.
   Uses a map file produced by any of the procedures listed above to produce a graphically symbolized map on a dot matrix printer.
5. Return to the main menu.

approach is used to create a new map from one or more preexisting maps. Filtering may be repeated with as many different maps as the user desires. For example, maps of land use, soil type, and political boundaries might be filtered to produce a map showing only those areas with a specific land use/soil type combination within a specified political unit.

Single maps or comparative maps may be summarized to present tabular information of statistics about the amount of each land use type or of each combination land use/soil type within the area. The summarization functions are supported by suitable statistical tests, such as chi-square and correlation analysis, as well as basic descriptive statistics.

Scaling, rescaling, and windowing functions are internal to each of the tasks mentioned in this section. At present, a projection function is not provided, although the capability is planned for future addition to the system. Given the assumption that the system will be used for small geographic areas, the earth's surface may be assumed to be
adequately represented by a Cartesian coordinate system so this is not regarded as a serious defect. The system does not provide its own digitizing capability because of the extreme hardware dependency of digitization.

3. THE PROGRAM

The facility with which any computer program performs its functions is partly a result of the programming language or languages in which it is written (Williams et al., 1987). USMGIS is written entirely in Ada for five reasons. First, most GIS functions involve a great deal of numeric processing and the language used must facilitate such processing. Second, since the program should be capable of operating on the largest possible variety of microcomputer hardware, the chosen language should minimize hardware dependency. Third, the program should consume the smallest feasible amount of memory, leaving as much space as possible for data. Fourth, the program should execute rapidly. Fifth, the program should allow maps of various sizes to be created efficiently.

Ada was selected because it was the only language which seemed to meet these criteria fully. Programs written in Ada rival those written in Fortran in numeric processing facility and equal or exceed them in execution speed. By including the necessary components of a shell, the Ada program minimizes hardware interaction and, thereby, maximizes the number of machines on which it can be used. Relative to a language like fortran, Ada produces very compact execution

code, largely because of its use of overlays and data heaps. Most important, Ada provides dynamic allocation of array sizes, allowing creation of the appropriate array size during execution rather than requiring array allocation in the original programs. From the authors' perspective, this feature alone justifies use of the language in an application such as this one.

4. CONCLUSION

The GIS program introduced in this paper is not ideal. It is certainly much less sophisticated than most commercially available GIS software. However, it is functional for the purpose identified at the outset in that it is capable of introducing students to most of the basic functions of geographic information systems and of performing the types of tasks most often needed by local governments and other users who deal with small geographic areas. USMGIS cannot and is not intended to compete with existing GIS software. Rather, it is designed to address a need left unfulfilled by existing software and to, hopefully, incorporate some cartographic improvements into GIS software design.

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EDUCATION ABOUT AND WITH GEOGRAPHIC INFORMATION SYSTEMS: ISSUES AND EXPERIENCES

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1. INTRODUCTION

Geographic information systems have not yet been put in their place, educationally speaking. Instruction and learning about or with contemporary computer based geographic information systems is a topic that is only now receiving attention (GOODCHILD, 1985, MULLER, THOMPSON, 1986). Most energies so far have been directed towards mastering the technological catalysts for the design and fabrication of geographic information systems, and reporting on very many practical applications in different domains.

But what of educational uses of geographic information systems? My intent in this paper is to raise a number of issues of substantial long run significance for geography teaching in a context of the emerging computer technologies likely to have profound impact on how we teach, and how we want students to learn, if only we can change the way we think about using computers. The computer evolution will go on even if our backs as educators are turned. I will identify the issues by comparing and contrasting the current and potential practices in geographic education with and about geographic information systems.

2. GEOGRAPHIC INFORMATION SYSTEMS SIMPLY DEFINED

Using a simple definition, an automated geographic information system is a toolbox for obtaining answers to (geographic) questions about the world, using data contained in the information system. The toolbox, consisting of software, hardware, and operating procedures, facilitates answers to different kinds of questions in varied formats. Of particular concern are the types of data and the kinds of operations that can be performed. Thus a geographic information system's differentiation from mapping or drafting/design systems lies in the analytical functions that can be undertaken. The data can be numeric, pictoral, or textual descriptions of selected attributes pertaining to distinguishable spatial objects, simple or compound.

There is no necessary presumption that a geographic information system is automated. We have used various other means for centuries to get answers to questions about the earth's surface and people living upon it, but today there are apparent benefits in using automated systems for some purposes. Even so, in a discussion of the educational role of geographic information systems it is advisable to separate the topic of the computer environment from the issues of content and use, at least until we reach the point of discussing educational delivery systems and modes of instruction.

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3. THE USE OF GEOGRAPHIC INFORMATION SYSTEMS IN A UNIVERSITY

I am looking at geographic information systems from the viewpoint of a professor in a university geography department concerned with teaching geography at different levels to students with a great variety of prior geography education and level of understanding of the world as the home of man. As a geography professor I believe I should use resources suitable for improving student learning of concepts, principles, and empirical facts generally regarded as appropriate and important in university geographic education. Consequently, a geographic information system is a resource alongside photographs, fieldwork, computer simulations, or textbooks, to aid student understanding. Of course, in this sense, an automated geographic information system generally provides some productivity benefits via the integrated nature of different data and options for using, managing, and displaying those data. However, the presumed benefits of current computer based geographic information systems have to be evaluated in the light of educational goals.

For the purposes of this paper I will consider the three institutional roles of a university, those of instruction, research, and community service, separately.

The service role, particularly important for public universities, has at times, certainly in the case of the University of Maryland at College Park, provided a basis for founding or developing an infrastructure for automated geographic information systems work. Projects for state agencies or other government bodies can and do provide a means of acquiring software or hardware, building databases, or gaining experience with the practical realities of geographic information systems, but are not intellectually necessary or even desirable for developing a geographic information system resource for general educational purposes. The service activities are more valuable in supporting the role of teaching about geographic information systems, for courses that deal with the institutional and social context aspects of data resources, such as the access by citizens to public information, or the success of monitoring and matching the actions and needs of the branches of executive and legislative government.

Current marketplace disequilibrium between consumers and suppliers of knowledge about geographic information systems seems to put pressure on academic institutions to be responsive to external communities via training programs and other aspects of technology transfer. However, businesses and government agencies should understand the teaching of geographic information systems is not the same thing as "teaching

ARC/INFO". Learning how to use particulr software could be an occasional service offering of a university academic department on a contractual basis, but is not the mainstream activity. In this regard, my second principal point about education with or about geographic information systems is that there appear to be no such external pressures (presumably logically associated with the pre-college levels of education) on the teaching of geography using the modern geographic information system software tools.

The research role for faculty and advanced students, through the activities of establishing new knowledge, incorporates a geographic information system resource appropriately to the extent that the toolbox improves the productivity of scholars in existing research fields or in opening up or facilitating work at research frontiers. In this regard, having modern research tools would appear to be axiomatic for universities, and, as a consequence, geographers, or other scholars, have a role to play in developing new tools, either themselves, or by encouraging others.

Here, my distinction between research with or about geographic information systems on the one hand leads into the controversial subject of whether geography departments should be engaged in developing tools, and, on the other, into the unknown territory of whether or not geographic information systems are being used for research in geography, let alone whether they have been shown to be valuable. I suspect that time will be the teller in both situations, very much as for the role of quantitative methods, but, for now, my point is that the two kinds of educational uses lead to different emphases, acquiring new knowledge versus conveying that knowledge to students.

The third mission of a university, education, my principal concern, has many facets, often wrapped up in particular philosophies about the purpose of education, or the role of geography as a liberal arts subject, and arguments about the current vocational bent of most university students. Absent any official profile as to what is taught in geography at the university level in the U.S.A., I will paint a general picture from limited information. There are general introductory geography courses, for example, Introduction to Geographic Principles; there are specialized introductory courses like World Metropolises or Maps and Map Use. There usually is a set of core introductory courses for intending majors, like Physical Geography, Techniques of Geographic Analysis; followed by numerous advanced substantive and techniques courses at the upper division level of undergraduate offerings.

Geographic information systems can fit into this structure in several ways, but today fits in most dominantly in the advanced techniques category. A parallel with the changing views towards quantitative methods during the 1960's and 1970's serves to provide some perspective, if only to point to the futility of a major debate about the "new techniques." More significantly, drawing on this comparison, a diffusion of geographic information systems technology to geographers will require means by which colleagues will be able to learn about the new teaching resource, development of an attitude that geographic information systems can be effective for pedagogic purposes, and that there will be a delivery system environment conducive to the use of geographic information systems.

Teaching about geographic information systems may have a shortage of knowledgeable people today, but at least there are courses in universities. I suspect we can count on two hands the number of non-techniques courses in which geographic information systems are being used for teaching geography. But rather than discuss technology transfer to immediate colleagues, let us consider some general educational goals that will influence the success of the technology transfer. Will geographic information systems cause long-lasting, valuable, and visible substantial change in what students learn or how they learn about the world? I have no doubt that they will, but we first need to consider what a geographic information system should consist of for general pedagogic use. My distinction here between education about and with geographic information systems is simply the difference between the end in itself, and the means to a different end.

Taking advantange of the inherent special fetures of contemporary computing technology (BORK, 1987a), a geographic information system should provide the means to learn concepts that are otherwise difficult to assimilate. Drawing on the example I shall use more fully later, in what way is a geographic information system a worthwhile resource for learning land use patterns and the processes that cause variations in land use in urban and rural areas? From this perspective, the concepts like spheres of influence of highways, and the transfer of two dimensional cartesian coordinate graph representations of a statistical relationship to two dimensional earth space patterns, as encountered in traditional von Thunen model type explanations, are handled with great difficulty by lower division college students. Creative software design using modern computer graphics and interactive computer use should be able to meet the challenge of improving learning as demonstrated by BATTY et al. The pressure on education with geographic information systems will then be to identify concepts that can be effectively learned with the aid of geographic information systems, a need quite different than that to be met when teaching abut geographic information systems.

4. THE FUNCTIONALITY OF A GEOGRAPHIC INFORMATION SYSTEM

Given the varied content, objectives, emphases, traditions, and pedagogic styles of geography courses, an appraisal of geographic information sytems must depend on determining the general classes of problems or concepts bein taught, and the particular tasks being performed, that is, the general domain and functionality. Which parts of geography teching might benefit? What kinds of queries are being made of a database? These issues are important to show the extent to which geographic information systems softwaru, generally commercially produced in response to market demand from government and business organizations, are inadequate or appropriate; or to reveal to naive colleagues the differences between mapping and geographic information systems.

Geographers of the locational analysis tradition are likely to be more receptive initially than those with humanist or environmental approaches to earth description. But surely we are talking about how geography is structured fundamentally, where geographic information system concepts may indeed be forcing us to think seriously about what that structure is, as suggested by GOODCHILD, 1985, and MULLER, and particularly POIKER who goes as far as to say: "We also believe that GIS can serve as a vehicle to educate geographers as the old humanists thought that Latin can serve for the education of young minds by structuring their thoughts." Concepts of movements, networks, nodes, hierarchies, and surfaces, using the Haggett structure (HAGGETT), or location, place, movement, regions, and human-environment interactions of the National Geographic Society (NATIONAL GEOGRAPHIC SOCIETY), are reasonable basics for a crude needs assessment, or an evalution of available software. Which commercial software can produce accessibility surfaces for a Loschian plane? Which commercial software can identify heartlands?

At a more detailed level, we may be able to make progress by establishing a frequency distribution of primitive queries of the kind listed as Figure 1, in order to ascertain the spatial operators needed for general educational purposes. At the same time, it remains to be seen whether systematic needs assessment, prototyping, or other software engineering techniques will be the appropriate tools to use for the educational application domain.

My distinction between teaching about and with geographic information systems in this regard is that for the former, it is generally sufficient to demonstrate principles of classes of functionality, but for the latter, we need to have specific functionality. If we are to continue along the track of general purpose geographic information

Union of spatial objects.

Intersection between spatial objects.

Difference between spatial objects.

Buffering around a spatial object.

Adjacency between adjoining objects.

Edge determination of spatial objects with different characteristics.

Windowing of spatial objects.

Shape of a spatial object.

Length computation.

Area measurement.

Containment within another spatial object.

Overlay between spatial objects.

What is the characteristic of a selected spatial object?

What spatial objects contain certain characteristics?

What are the collective characteristics of a selected spatial object?

What is the characteristic of all spatial objects?

Figure 1 PRIMITIVE QUERIES FOR NATURAL RESOURCES ANALYSIS AND MANAGEMENT
(Source: TSAI)

systems, much as has been quite standard for statistical analysis software for educational purposes, then we must establish the particular operations needed. The needs are greater than can be met currently in a single software system.

5. THE INFORMATION SIDE OF GEOGRAPHIC INFORMATION SYSTEMS

Analytical modelling, or manipulating data via a variety of spatial operators, are only part of a comprehensive geographic information system. The database implied by the information segment may be a more immediately powerful component of a geographic information system for educators. Indeed, just as for government agencies the emphasis for many is the ability to get at lots of data easily, let us not forget the profesor who walks in the inadequately furnished classroom with rolled up wall map, slide projector, and chalk. A geographic information system is a multi-media data resource for teaching about the world.

Identification of some of the characteristics of data used by geographers, traditionally very visually oriented, is helpful in providing a basis for evaluating geographic information systems as a database resource. Geographic concepts are taught with the aid of photographs of landscapes, videotapes of cloud formation dynamics, field sketches of erosion surfaces, thematic maps of the distribution of mortality rates, and graphs for sediment composition. Where is there a geographic information system that allows users to get at pictures, movies, text, numbers, maps, and graphs? A multi-media database is what I as a professor of geography would like to have available. My department has experimented with videodisk use in classes; the BBC has produced a marvellous resource, the Domesday disk, for teaching geography and history in Britain (GODDARD and ARMSTRONG, RHIND and MOUNSEY, OPENSHAW and MOUNSEY, OPENSHAW et al.), and the David Sarnoff Research Center and General Electric Company demonstrated just two weeks ago in Washington, D.C. a computer based multi-media system suitable for geographic browsing, or simulating the real world in a classroom (MORRIS).

My concluding principle here is that geographic education uses, and needs, much more than quantitative information. Pictures bring the real world to life. Graphs convey relationships in complex processes. And while teaching about geographic information sytems may not use multi-media data resources, it, however, also must deal with pictures, for example, the data structures and processing techniques for dealing with image data.

6. THE MODE OF INSTRUCTION

A comprehensive consideration of geographic education with geographic information systems must also include discussion of the mode of instruction and delivery systems, that is the pedagogic style and objectives, and the resource constraints. It is well established that class size above about eight or ten students has little impact on what is learned, but a large class size is important from the teacher well-being and delivery system resources points of view. Small classes, tutorials, and individual dialogs with instructors are more beneficial to students. In this regard many people view computers as having great future potential for individualized learning.

Today, in geography education, computers are generally used for little more than numerical data computing, word processing, or making trivial maps (FORER, SHEPHERD, REEVE). We have lots of tools, especially software for microcomputers for making thematic maps, but how much of the software has been designed with pedagogic goals in mind? We have computer tools, we do not have computer based lessons for individual student learning, whether for remediation, supplementation, or exploring new worlds.

My own limited survey three years ago of the use of software for spatial data handling indicated only four courses out of 67 were "non-techniques courses". The frequency of mention by major category, for the 30 geography departments responding, were computer mapping - 17, quantitative methods - 11, remote sensing - 9, modelling - 8, computer methods/data processing - 7, geographic information systems - 6, other cartography - 5, and other - 4 (THOMPSON, 1986). My suspicion is that there has been little change in this pattern in three years since that survey.

Even if we consider only classroom presentation with computer resources, let alone the interactive, and interesting individualized software yet to be produced for geographic education, the fundamental question surely is to improve learning. Given resource constraints, and an absence of multi-media geographic information systems, it appears prudent to start with good resources suitable for the classroom presentations. In this regard teaching about geographic information systems is different - personal hands-on experience with software and hardware is an important part of learning practical realities. The experiential learning may even help in understanding basic concepts of data structures, algorithms, and data quality, as well as provide experience with a range of software functionality and graphics peripheral devices for input and output.

7. DELIVERY SYSTEMS - THE REALITY OF RESOURCE CONSTRAINTS

The ability to adopt effective teaching strategies depends in part on resources available for different delivery systems. Well equipped teaching classrooms for video projection of computer produced images are rare; laboratories that are more than a collection of computer terminals of microcomputers are not too common. Convincing administrators of the need for high quality video projection, or that a laboratory is a place for people to work together on similar projects, sharing software, hardware, data, and people resources, takes a long time when the perceived market (geography education) is small.

My concept for a laboratory for supporting geographic education is a spatial learning laboratory with multi-media hardware, and geographic information systems software that handles picture as well as other data and includes learning devices such as self-testing, test-generators, or context sensitive tutorials. In this matter I do not see any difference in style between learning about or with geographic information systems. Two-monitor displays and individualized computer learning software are applicable in both cases. However, today many laboratories are technical course oriented, as described by Berry, Foote and others (BERRY, FOOTE, SCARPACE et al.).

Resource needs, for hardware, software, and personnel, are not modest if we are to cater effectively to laboratory courses with twenty or thirty students. Fifteen workstations do not go very far for an introductory course of 500 students. Software production and delivery issues clearly include the scale of production, the development or delivery hardware difference, use of computers only or other media, single screen or multiscreen workstations, or electronic podiums (BORK commented on some of these issues recently).

8. AN EXAMPLE - UNDERSTANDING WORLD AND LOCAL LAND USE PATTERNS

For some time my department has used the Marble and Anderson LANDUSE program for helping students learn about the processes behind observed land use patterns. We have used this fine, non-interactive, non-individualized program as supplementary to traditional classroom and textbook exposition, aided by simple examples of real world conditions, graphs of location rent gradients, maps of land use patterns, and examples of computations using the underlying deterministic linear equation with just a few variables (MARBLE AND ANDERSON).

In 1973 we used this program with 100 students working with one clunking teletype machine. In the early 1980s we were able to use the same software in several classes accesing a minicomputer from a computer terminals laboratory, and now the software runs on an IBM AT computer, taking 15 minutes to do a simple simulation. The program works; the three faculty who have used it believe it has improved learning for most students, but is this porting of a single program, unmodified, making educational progress? Not if we judge according to the technology capabilities of 1986 compared to 1973. But to come to the thematic part of this paper, geographic information systems, what is the role for such software in teaching concepts like land use that are multidimensional and hard to visualize. The spheres of influence map (Figure 2) from that simulation program summarizes several needs - map display for differentiating among highways, algorithms for finding optimum paths from origin to market on a non-uniform plane, and computations for attributes and spatial properties of point, line, and area objects. Going beyond the simulation program itself, imagine the incorporation of picture data, graphs for distance decay, non-linear functions for the scale economies or demand curve.

The requirements of a structured lesson can be like one simple scenario shown as Figure 3. Although this appears in sequential fashion, think of the teaching mode as one of switching among pictures, graphs, data, simulations, and text, at will, as dictated by the needs of an individual student. The challenge lies not in developing geographic information systems per se, but in designing them as resources and toolboxes for facilitating learning difficult concepts that are valuable in understanding the world in which we live.

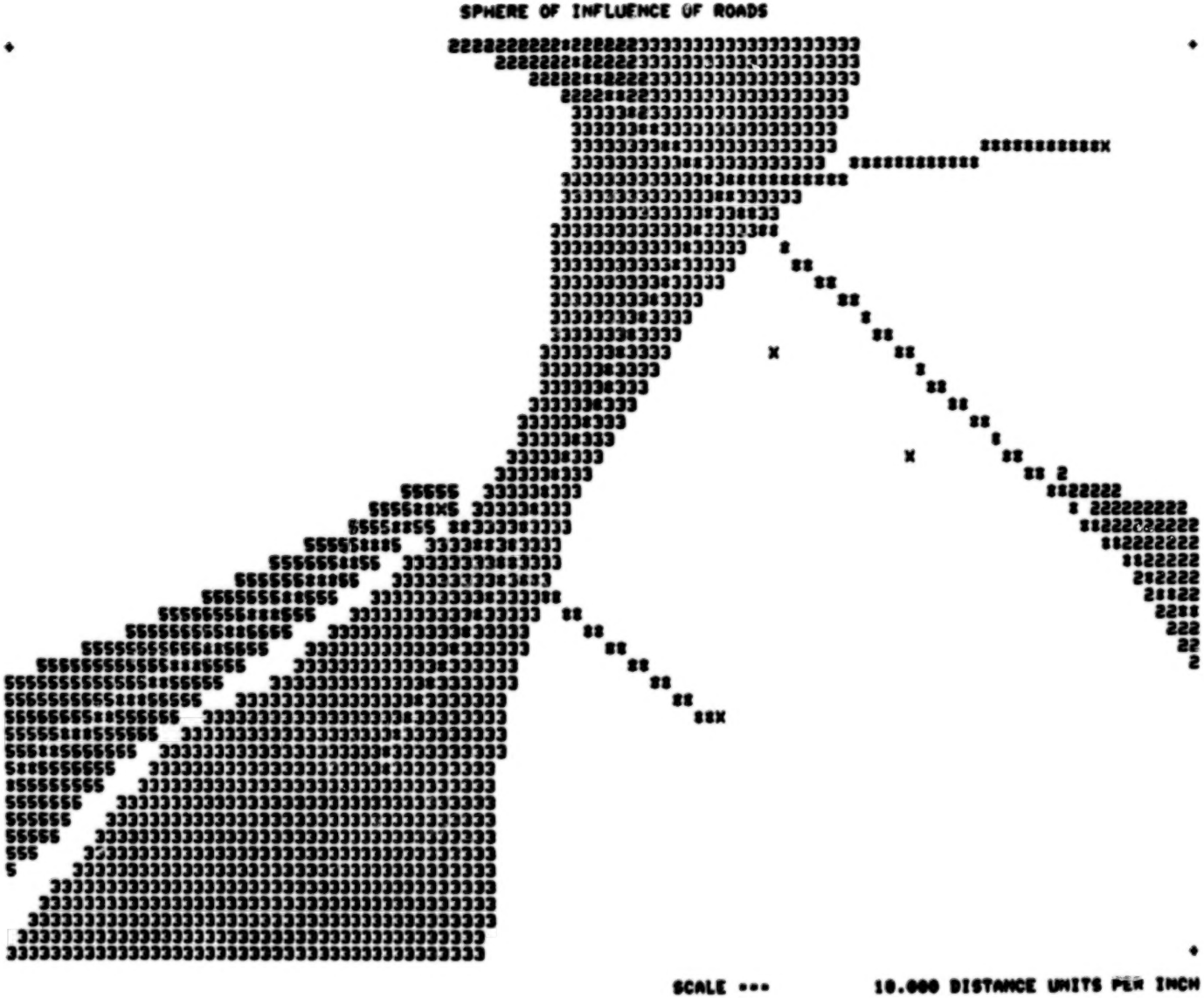


Figure 2 SPHERE OF INFLUENCE OF ROADS

Figure 3 LESSON OUTLINE FOR LAND USE SIMULATION

1. Students to study some video disk based pictures showing land use in different environments and regions of the world. Some of the series of frames will be maps, some slides of countryside.
2. Some material on the pictures/maps will be emphasized by graphic overlays.
3. Students will be asked to point to some features on the frames as part of an initial activity.
4. Textual material will be presented, possibly varying depending on responses in (3), that is, indicative of prior knowledge. Frames of text.
5. Opportunity for hierarchical type exploration of written material -- printing to a keyword in text will bring up frame(s) of more detail.
6. Material should be studied by the student, with opportunity to go back and repeat all or some of the sequence.
7. Multiple choice test on the material. Responses are recorded; time to answer is recorded; subsequent actions are recorded.
8. Branching to earlier or new (remedial) or new (advanced) material depending on answers.
9. Initiate lesson (section) on simulation by showing real and schematic maps of a land use pattern. Real map on videodisk; schematic prepared by graphics editor and loaded as a picture.
10. Discuss theory of land use patterns via text and introduce tables of data (e.g. Canicatti, Sicily) to support the theory.
11. Present simple graphs of the relationship of profit to distance from a market, using line drawing and color shading.
12. Some questions to students to assess their understanding of graphs.
13. Present a mathematical equation that relates to the linear profit-distance relationship; give sample data as a table; give example of computations.
14. Let students problem solve by computing some values and making a graph. Generate data by random selection from preset values.
15. In order to make maps and do extensive computations provide students access to a FORTRAN program that already exists, and let them execute that program on data to be made available to them also.
16. Allow substantial time for this activity, provide some assessment mechanism and opportunity for student comments.
17. Now give a test to the students, with appropriate recording.

9. A NOTE ABOUT OUR MARYLAND SITUATION

To the extent that the geography profession wants to worry about educational issues, and I believe it should, then I will sketch in some of our experiences at the College Park campus of the University of Maryland as possibly of value to others. Teaching geography with geographic information systems, even the non-picture data variety, is still virtually non-existent. However, last year we experimented with the use of a videodisk based lesson glaciation. This semester we are conducting a controlled experiment in two sections of our largest introductory geography couse, exploring the impact on student learning (recall and retention) of computer based graphic materials used for classroom lecture presentations and an individual student oriented workstation lesson on world agriculture.

Teaching about geographic information systems is now well established, being supported by a traditional computer mapping type laboratory with a range of hardware and software. The physical part of the laboratory contains six Tektronix graphics termainals, both storage tube and color raster, five digitizers, four pen plotters, and paper (ink jet) and photograph (film recorder) type output units. The terminals access IBM or SPERRY mainframe computers, but are used primarily in conjunction with a PRIME minicomputer system, developed in part with the aid of state agencies. There are numerous IBM AT and PS/2 microcomputers that can be used standalone or as terminals. Software is available for mapping, remote sensing, geographic information systems, spatial modelling and problem solving, digitizing, and learning about glaciers, world agriculture and land use. Clearly the emphasis has been on support to technical courses, but that orientation has been changing in the past two years through the experimental work of a project to develop curriculum materials for general undergraduate education.

The software for geographic information systems consists of ARC/INFO, which we soon will have available institutionally on mainframe, minicomputer, and personal computers; MAP and GRID on a minicomputer, with a pathway from ARC/INFO to GRID to MAP; some of our own software originally developed for political redistricting (THOMPSON and SLOCUM, 1982); and, via the courtesy of Hanan Samet in the Computer Science Department, access to the prototype quadtree based system, QUILT.

In general, administrative support has been forthcoming for particular software acquisition and additional workstations. Recently, the classroom presentation delivery system has been enhanced by the acquisition of video projectors, videodisk players, and most recently, a

new 37 inch Mitsubishi high quality "multi-synch" monitor than can handle input from Tektronix, IBM PC or PS/2 computers, and standard NTSC video sources. Administrators are responsive to educationally oriented projects, providing summer salary support for faculty and assistants, centralized programming advice, and hardware via grants from Apple, IBM, and Sperry corporations. Self-learning opportunities are becoming available, at least for computer workstations, although not yet for the right software or multi-media databases.

10. PLANS FOR THE FUTURE - GEOGRAPHYLAND

It appears that the climate is right, technologically and institutionally, for developing instructionally oriented software using geographic information system concepts or toolboxes. I believe that learning is the issue, not technology; and that the emphasis should be on teaching with geographic information systems at least as much as on teaching about geographic information systems. I envisage building student insight intuitively via controllable, manipulatable multi-media worlds created by interactive software using an embedded geographic information system toolbox. This GEOGRAPHYLAND will make the real world live in the classroom.

Along the way to that somewhat Utopian dream, I see contemporary geographic information systems used more widely. Using Figure 4 as a summary, such systems will be seen primarily as a database resource for introductory general education courses. For the second level, core courses, geographic information systems will be used partly as multi-media data bases, and partly for analytical and modelling fetures, as might be needed in explaining land use patterns, inequities in political representation, or water budgets. In an introductory geography techniques course for the same level, already in a planning phase, a geographic information system will be used as an integrator. At the advanced upper division level an appropriate geographic information system should be able to handle many types of problem, pure and applied, such as biases in information surfaces of individuals, or determining target areas for rezoning land for commercial purposes.

Figure 4 ROLE OF GEOGRAPHIC INFORMATION SYSTEMS FOR DIFFERENT COURSES

INTRODUCTORY GEOGRAPHY COURSES	- G.I.S. as a multi-media data base resource
CORE COURSES FOR MAJORS	- G.I.S. as a data resource and some analytical functions - G.I.S. as a synthesis is a techniques course
ADVANCED UNDERGRADUTE COURSES	- G.I.S. as a toolbox for problem solving

In this type of pedagocially driven endeavor there will be several challenges to geographers and the geography profession in teaching with geographic information systems that are not present in teaching about geographic information systems. The educationally based issues concern discussion about the best ways to use computers, technology transfer to computer ignorant colleagues, institutional support for educational projects, and identification of subjects tht have a high probability of success in improving learning by students. Other issues, technical in nature, are shared by both educational needs - development of better data models, data structures, algorithms, and hardware for geographic information systems.

But in the long run we may also learn how to structure geographic education, we may be able to make a complex world live in the classroom, and we may be able to convince others that there is some value in geography. I am inclined to downplay the serendipitous value to geography itself by thinking about geographic information systems content and structure, but it is hard to escape the discovery by non-geographers active in the development of geographic information systems, that spatial organization is a good way to structure problems, as an integrating foundation for real world problem solving. (DANGERMOND).

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GIS TRAINING AND THE EVOLVING MARKETPLACE

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ABSTRACT

The College of Geographic Sciences in Lawrencetown, Nova Scotia, has provided GIS training for several years. As the marketplace has evolved, it has been necessary to modify and expand the curriculum to reflect the new demands.

The paper describes specific activities at the College and then presents a discussion on the following five issues:

1) the technical training niche
2) computer technology trends
3) job skill requirements
4) diversification of applications
5) international training

These issues represent some of the forces which are affecting the direction of our training.

1. INTRODUCTION

There are several indicators which suggest that GIS technology is experiencing a sharp increase in demand; e.g., new journals, vendor sales, and consultant reports to special committees (Tomlinson, 1986). At the same time, there are indicators which suggest that the education system is not equipped to meet this demand; e.g., vacancies for GIS faculty, high demand for GIS specialists from existing programs, and the establishment of new programs.

In this paper, the author provides a perspective on GIS training and the effects of the evolving marketplace. While the first part of the paper describes the specific experiences at the College of Geographic Sciences, it is believed that the issues are pertinent to all educational establishments seeking to respond to the needs of the GIS industry.

2. HISTORICAL PERSPECTIVE

In 1980, the College of Geographic Sciences (formerly known as the Nova Scotia Land Survey Institute) established a one-year diploma program in Scientific Computer Programming. At the outset, there was

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a requirement to identify fields of applications based on instructor expertise, which would form a context for application programming. One of the core applications was the programming and use of Geographic Information Systems. The first system implemented at the College was POLYGRID, a system developed by G. Langford & Associates for the Alberta Government. This system was converted from the IBM mainframe environment to the PRIME minicomputer in Lawrencetown. It represented a vector data capture environment with vector to raster conversion, followed by raster analysis and display.
In 1982, the availability of the PRIME computer led to contact with ESRI in Redlands, California, and the subsequent installation of both the GRID and PIOS products. Within the year, these systems were superseded by the arrival of ARC/INFO. Over the next two years, the College trained programmers who were knowledgeable in the programming components of this system. In particular, Fortran 77 was used with the ESRI libraries, INFO programming was applied to data base management system ,and CPL was programmed for the development of higher level tools. By early 1985, it was clear that it was not possible to confine GIS programming within the original diploma program. The result was the creation of a separate GIS program which would be completed within a one-year period and would build upon the pragmatic philosophy of the Department of Computer Programming at the College.

3. DIPLOMA PROGRAM IN GIS

The GIS training program was designed using the same model as the other computer programs (now Scientific Computer Programming, Computer Graphics Specialist, and Remote Sensing) (Maher & Wightman, 1985). It included three components (see Figure 1).

1) programming language skills
2) theoretical concerns
3) applications

In addition, the program, like all of the other programs in the department, included a cooperative project for each student. These projects are established with the marketplace, whether government or industry and whether vendor or user.

Appendix A lists projects completed in the last two years of the program; i.e., 1985-87.

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4. STATUS OF THE GIS PROGRAM (1987)

This fall we enter the third year of this specialized GIS training. With changes in instructional staff, the availability of new software, and to a limited degree, new reference sources, the curriculum has been modified and expanded. The changes are reflected in Figure 1.

During the first semester, we introduce both minicomputer and microcomputer GIS with a major emphasis on the vector arc-node data structure of ARC/INFO and less time on the raster quadtree environment of SPANS. The other expansion has been to provide GIS students with formal training on the Aries image analysis system. As the result of these additional products, we have developed a non-system specific course entitled Fundamentals of GIS, using a new text (Burrough, 1987). To accommodate these additions to the first semester, we have dropped a mathematics course.

Second semester additions include exposure to the CARIS and pcARC/INFO systems and language development in C and AML. These expansions reflect the increased use of C in GIS and the utilization of these other products in the Canadian marketplace. With staff changes, we were unable to offer the mathematics for the GIS course which had been presented by Dr. C. Gold in the past.

At this time, the third semester will follow the traditional pattern. There will be a major focus on cooperative projects (40% of elapsed time), a need to gain exposure to different DBMS, plus an awareness of algorithmic development and data transfer issues. The net effect of these modifications will be an increased intensity with stronger application emphasis and a reduction in mathematical/theoretical concerns. For the graduate, this should result in a broader market awareness; for the instructor, in order to achieve these objectives, there will be an additional effort to master new systems.

Given the nature of GIS training at the College, we have close ties with the industry through the number of vendor systems on site (see Figure 2) and also as the result of the cooperative projects. Unlike the university environment, the mandate of a provincially funded training institution is to place our graduates in the marketplace. It is, therefore, incumbent on the instructional staff to maintain the curriculum and equipment resource in tune with the market demand. From this perspective, five issues have been identified for discussion:

- 4.1 the technical training niche
- 4.2 computer technology trends
- 4.3 job skill requirements
- 4.4 diversification of applications
- 4.5 international training

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4.1 Technical Training Niche

At the College, because of our historical roots, we have chosen to focus on the programming skills required by the industry. In part, this reflects the use of ARC/INFO as our primary model. This system is marketed as a tool box, and as such it provided a rich environment for the development of programming skills through practical assignments. Within this context, we produce tool users, but we do not in general, develop tool makers. This task we recognize better fits into the university environment, where there is more time for practitioners to create new concepts or algorithms.

In this training role, we are not selective with regards to academic discipline. The technology is being applied to a wide range of fields. Intake into the program reflects this diversity, where we have in the same year foresters, geologists, geophysicists, survey engineers, computer scientists, and geographers.

With the increasing number of installations and also the experience of earlier systems, the market is demanding technical managers who are familiar with GIS concepts and understand the technical issues. There exists a requirement to complement the technical training with post-graduate learning in a specific discipline where there is both an appreciation for spatial processes but also policy matters as applied to GIS technology.

4.2 Computing Technology Trends

At the College, with our market orientation, we are expanding from a single mini-based training environment to multi-system micro and mini-based GIS training. This reflects the establishment of technology collaboration programs between industry and the College, but also trends in the market. In responding to these pressures, we require students to gain familiarity with several operating system environments (PRIMOS, VMS, AND MDOS), broaden their language base (Fortran and C), and appreciate different data base management systems (INFO and INGRES).

While this array of environments is expensive in terms of the load on our human resources, it is unavoidable given the training mandate of the College. In an academic setting some of this multiplicity of vendor product can be reduced; however, the combination of micro and mini-based GIS does reflect the present marketplace.

4.3 Job Skill Requirements

Over the last five years, we have noticed a shift in the job requirements. At the outset, the need was for technical support staff who could manage a GIS installation, or write Fortran or INFO programs. This requirement still exists since installations are dependent on personnel with a certain level of computing skill.

There are, however, two noticeable trends:

1) data base designers 2) technical authors

For those GIS installations which use a DBMS as part of their software, there is a growing demand for staff who can interpret the usage requirements of the GIS into an efficient data base design. At the College, we are attempting to address this need with investigations into current approaches in forestry and municipal planning.

In the competitive market, the ability to communicate clearly concepts, procedures, and application case studies to the user community is critical to the vendors. Certainly, we work with sufficient different systems that we know that there is a shortfall in technical authors. As we attempt to satisfy requests for this type of skill, there is recognition that it requires special communication talents placed within a context of practical familiarity with the tools of GIS.

4.4 Diversification of Applications

Given the nature of GIS where it is concerned with the manipulation and analysis of map information describing the earth's surface, it is hardly surprising that for every ten installations, one will be in a significantly new field. Since we operate an intensive one-year technical training program, we have difficulty keeping abreast of this diversity. Our approach has been to focus on the common concepts and technical skills. Each year we will modify our application field of interest. Since our intake of students is varied, we use the cooperative project to allow concentration on the individual application area.

From our experience in Canada, we have shifted our focus over time. Three years ago, it was forestry; this year we shall take a closer look at municipal planning. Perhaps in a year or so it will be geology and then within five years ocean applications.

4.5 International Training

Vendors are increasing their market presence across the world. To date, we have been training for the North American market where we understand the cultural and educational background of our students. In addition, we are somewhat familiar with map sources, their availability, projections, and quality. At this time, we see a number of new installations in the Far East--Malaysia, Thailand, and Indonesia. As we try to respond to the training needs of these countries, it is apparent that there is considerable learning required at the College. We need to understand the cultural and educational context, the institutional framework, and the role of the North American vendor in this different environment.

5. CONCLUDING COMMENTS

The College has established a solid reputation for the provision of well skilled technical staff to the GIS industry. We see the demands of the marketplace becoming more diverse: computing technology, applications of GIS, and job skill requirements.

If the larger academic community is to respond to these increased demands, then GIS training, as exemplified at the College, must be integrated into the broader context of GIS education. This translates into higher degrees in Geography and other disciplines, which utilize the technology. To make this learning cost effective, it may be necessary to establish twinning relationships between the technical colleges and the university departments, or develop new institutional arrangements.

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1985 CURRICULUM

Semester 1

GIS 101	Introduction to Computers
GIS 102	Topics in Mathematics
GIS 103	Fortran Programming
GIS 104	Applications of GIS
*GIS 105	CPL and INFO Programming

Semester 2

GIS 201	Comparative Systems and Further Applications
GIS 202	Mathematics for GIS
GIS 203	Advanced Fortran and Data Structures
GIS 204	Group Cooperative Project

Semester 3

GIS 301	Algorithms
*GIS 302	Data Transfer
*GIS 303	Data Base Management Systems
GIS 304	Individual Cooperative Project

1987 CURRICULUM

Semester 1

GIS 101	Introduction to Computers
GIS 102	Fundamentals of GIS
GIS 103	Fortran Programming
GIS 104	Applications of GIS (ARC/INFO and SPANS)
*GIS 105	CPL and INFO Programming
*GIS 106	Introduction to Image Processing

Semester 2

GIS 201	Comparative Systems & Further Applications (CARIS and pcARC/INFO)
*GIS 202	C Programming
GIS 203	Advanced Fortran and Data Structures
GIS 204	Group Cooperative Project
*GIS 205	Advanced Macro Language (AML)

Semester 3

GIS 301	Algorithms
*GIS 302	Data Transfer
*GIS 303	Data Base Management System
GIS 304	Cooperative Project

* half credit. All other courses are full credit.

Figure 1 - Curriculum Changes 1985-87 for Diploma Program in Geographic Information Systems

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Hardware

Processors	Devices	
	Input	Output
PRIME 550/II	7, Tektronics 4107 graphics terminals	1, Tektronics 4691 color copier
PRIME 750		
VAX 11/785	2, Tektronics 4115 graphics terminals	1, Tektronics 4695 color copier
2, PDP 11/73	1, Tektronics 4112 graphics terminal	1, Nicolet/Zeta 3653 drum plotter
5, IBM/AT		
	5, Calcomp 9100 digitizing tables	1, Calcomp 5734 electrostatic plotter
		1, Lasergrafix 800 printer

Software

GIS

ESRI: ARC/INFO

GEOBASED: STRINGS

Universal Systems Ltd: CARIS

ESRI: pcARC/INFO

TYDAC: SPANS

Yale University: MAP

Harvard University: IBM PC MAP

Image Analysis

DIPIX: 2, Aries II Workstations

CAD

PRIME: Medusa

Auto CAD

Mapping

KERN: MAPS 200/300

GIMMS

Atlas

Figure 2 - Hardware and Software Resources at the College

APPENDIX A

COOPERATIVE PROJECTS UTILIZING GEOGRAPHIC INFORMATION SYSTEMS (GIS)

GIS COOPERATIVE PROJECTS, 1986-87

NAME	TITLE	AGENCY	APPLICATION
Borowiecki	Automated Terrain Analysis with the ESRI TIN Package and USGS Digital Elevation	ESRI Canada Toronto, Ont.	Geomorphology
Brothers	Conversion of Area Master File and Population by Blockface Data for Halifax-Dartmouth Metropolitan Area into ARC/INFO	ESRI Canada Toronto, Ont.	Urban Planning
Caldwell	CARIS-NF Data Transfer	Statistics Canada Ottawa, Ont. UNB, Fredericton, N.B.	Methodology
Leeman	Plot Optimization in ARC/INFO	Trillium Data Group Ltd. Markham, Ont.	Methodology
Feldman	A Utility to Facilitate the Display of Map Browse Files	TYDAC Ottawa, Ont.	Methodology
Gertridge	Integration of External Data into CARIS	DREA, Dartmouth, N.S. UNB, Fredericton, N.B.	Methodology
Gillis	Transfer Software to Convert CARIS Data into ARC/INFO	Land Registration and Information Service Summerside, P.E.I.	Methodology
Hamer	Forestry Based Query Update System for PC ARC/INFO	J. D. Irving Saint John, N.B.	Forestry

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Hemming	DLG-GINA-DLG File Format Transfer	Geovision Ottawa, Ont.	Methodology
Hildebrand	IMAGIN and RASTERPOLY: generic utilities for bringing raster data into ARC/INFO	College of Geographic Sciences Lawrencetown, N.S.	Methodology
Hunt	Spatial Search on .PAT Files Using PC INFO	Fraser Inc. Edmundston, N.B.	Forestry
Hutchings	Conversion of CIS and Offshore Morphology Data to ARC/INFO and the Application of ARC/INFO Functions to the Generated Coverages	Bedford Institute of Oceanography Dartmouth, N.S.	Coastal Geomorphology
Johnson	ARC/INFO Pilot Project for the City of Halifax, Water Utility	Public Utilities Commission City of Halifax, N.S.	Urban Planning
MacDonald	ARC/INFO Correction of Relief Displacement at Data Capture and Data Loading from Aerial Photographs	N. S. Lands & Foress Truro, N.S. ESRI Canada Toronto, Ont.	Methodology
MacNairn	Map Projections Manual for ARC/INFO	ESRI Redlands, California	Technical Writing
McCulloch	CLDS Grid -ARC/INFO Conversion	CLDS, Environment Canada Ottawa, Ont.	Methodology
McGorman	Implementation of the MAP Librarian Subsystem of ARC/INFO	J. D. Irving Saint John, N.B.	Forestry
McKay	GBF/DIME-GINA-GBF/DIME File Format Transfer	Geovision Ottawa, Ont.	Methodology
McKay	Topographic and Property Graphics: Window and Query	USL, Fredericton, N.B. LRIS, Fredericton, N.B.	Urban Planning

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Ma J.	District Consolidation Using ARC/INFO	City of Tacoma Washington, U.S.A.	Urban Planning
*Ma T. *Morse D.	Integration of Remotely Sensed Data (Landsat, MSS, TM, SPOT) with Digital Cartographic Data (ARC/INFO)	McMillan Bloedel Nanaimo, B.C.	Methodology
Morton	Transfer of Data from Geobased (STRINGS) to ESRI (ARC/INFO) Using Optional DLG Format	College of Geographic Sciences Lawrencetown, N.S.	Methodology
Munroe	On-line Query System to the Parcel Data Base in Text and Map Format	City of Tacoma Washington, U.S.A.	Urban Planning
Pierce	Mapping Procedures for the Maritime Breeding Bird Atlas	N. S. Museum Halifax, N.S.	Cartography
Timmins	An Efficient Algorithm for the Calculation of Line Intersection & Polygonization in GIS	College of Geographic Sciences Lawrencetown, N.S.	Methodology
Violette	Task HL: Hard-copy Output Files for QMS Lasergrafix Printer from Aries II Files	College of Geographic Sciences Lawrencetown, N.S.	Remote Sensing
Vosyka	Forestry Modelling	TYDAC Ottawa, Ont.	Forestry
Zeller	A Workbook for PC ARCPLOT	ESRI, Redlands, California	Technical Writing

*joint project

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G.I.S. IN AN UNDERGRADUATE GEOGRAPHY PROGRAMME

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ABSTRACT

A course in Geographic Information Systems was introduced into the programme in Applied Geography at Ryerson in 1981. Responding to the perceived opportunity for geographic data analysts, course goals were aimed at providing a generic level of understanding of the utility and application of G.I.S principles. This was primarily gained through site visits, exercises simulating G.I.S. operations and hands-on experience via special arrangements with systems in the Toronto area. Particular attention was aimed at gaining an understanding of the conceptual models of systems and how they related to the information needs of the host agency.

Significant changes in the nature of new systems have been obvious over the past few years and our curriculum has been adjusted. Among the changes accomodated have been the proliferation of turnkey systems, the evolution of thought regarding the relationship between G.I.S. and Geography as a discipline, and the roles played by graduates with a baccalaureate degree in Geography. In an Applied Geography programme such as at Ryerson, continued refinement of the curriculum is taking place as new developments in the G.I.S. field are anticipated.

G.I.S. IN APPLIED GEOGRAPHY

It might be argued that interest in Geography arises from the genetic significance of location in evaluating other phenomena. We concern ourselves with the distributions of features since where they are found provides some fundamental understanding of why they are there. Geography, like other sciences examines phenomena of interest by initially describing them, perhaps accumulating an inventory of interesting properties, followed by attempting to explain the observed attributes, with the aim of predicting or extrapolating into unobserved situations. The ultimate objective in this sequence, which is commonly lacking in geographic education, is the application of this accumulated knowledge to decisions regarding the management of ourselves and

our environment. G.I.S. can be regarded as a means for this objective - the application of geography into the workplace. The Applied Geography Programme at Ryerson has attempted to introduce students to the practicalities of dealing with geographically distributed phenomena, and this has increasingly involved using a G.I.S. framework. This presentation addresses some of the issues encountered in providing a practical education for Geographers who will probably become G.I.S. users.

GEOGRAPHERS AS SPATIAL DATA ANALYSTS

Over the past six years the Applied Geography Programme at Ryerson has included Geographic Information Systems in its curriculum in a variety of forms. Initially responding to a perceived growth in demand for people with an ability to utilize computers for spatial data analysis, a one-semester "specialty" course was introduced into the fourth year of the programme. The intended purpose was to focus students' attention on the integration of geographically-referenced databases into the day-to-day operations of private and public sector agencies. Specialty courses in the department's four streams - Location Analysis, Recreation, Urban Geography and Resources/Environment - had a well established tradition of utilizing the mainframe computing environment in the completion of practical exercises, but contacts with the workplace indicated the need for formal training in G.I.S. Some of our graduates were being hired for G.I.S. positions based on their applied perspective and analytical experience despite, very limited exposure to this new technology in G.I.S..

Establishment of a curriculum was modeled on the observed situation in G.I.S. workplace applications in and around Toronto at the time. Although specialists other than Geographers played major roles in the operation of the systems, a potential career path for Geography graduates was apparent. Acting as an interface between the programmers/system designers and the ultimate decision-maker, the Geographer formulated the manager's information needs into specific data requirements for the data base administrator. Data were then extracted and abstracted using a variety of often geographical analytical techniques and synthesized into a report to the decision-maker. Since almost all systems at that time had been developed in-situ, the system designer was on site and often had a large staff of programmers to customize routines as new expectations evolved. The Geographer's role as spatial data analyst was clearly distinct from those of the programmer and operator.

In order to fulfill this role, a graduate was expected to have a generic understanding of the components of a G.I.S., including methods of identifying location, major hardware devices, measures for ensuring data quality, and objectives of the search, measurement and comparison capabilities of the system. Other topics addressed included the utility of integrating analytical and data storage capabilities for geographic data, and relationships between an agency's conceptual model and its specific information needs. Topics such as location identifiers, and internal workings of the computer were introduced out of necessity. Site visits to selected G.I.S. applications were used to demonstrate the integration of database operations with spatial analytic procedures, and formed a major component of the course. Emulation of this integration was demonstrated using standard statistical packages such as BMDP, SPSS and SAS. SYMAP and SAS/GRAPH represented the only manageable opportunities at Ryerson for computer mapping integrated with analytical procedures, and were restricted to the academic mainframe. The analytical procedures of statistical packages were not spatial per se, and batch processing without previewing plotted output, provided for considerable frustration for students, computing staff and faculty. Cooperation and generosity on the part of the City of Toronto and COMPUSEARCH, a commercial location-analysis data base, resulted in our students also performing assignments on 'real' municipal and demographic systems. Data quality and organization issues were introduced in the guise of relatively simple file manipulation and data extraction exercises. In the COMPUSEARCH assignment, data requests were submitted remotely via a phone modem attached to one of the departmental microcomputers. For many students this was their first exposure to a micro, a modem, and a data base. Curriculum issues were primarily focussed on the context of the systems, rather than on operations, and this was seen as both a weakness and a source of embarrassment in an applied programme. A decision was made to move the course to the third year to enable introduction of principles prior to the students' internship experience, which provided some operator-level knowledge of specific systems for many of the students.

CURRICULUM EVOLUTION - DEPARTMENTAL ACQUISITIONS

Changes in G.I.S. applications have been very apparent in the last few years. Most notable among these has been the proliferation of smaller commercial 'turnkey' systems. The organization of the newer G.I.S. applications had shifted to a condition of a manager who was more computer-literate, and expected both data base management and data analysis from limited staff. The roles of decision-support staff had converged. Systems now required less programming and the algorithms were now

managed by software releases which needed installation and updating. Large mainframes were being replaced by mini or enhanced microcomputers, often in some distributed processing arrangement. The tasks performed by some Geographers had expanded into operations management and other activities such as user needs analysis, system selection, benchmarking, and testing. Substantial revision of curriculum would be needed to simulate these working conditions. Instead, it seemed advisable to acquire a system, but the administration understandably balked at investing the necessary capital for the benefit of what appeared to be a single course. When the Ontario Government announced the availability of special funding to enable Universities to upgrade their computing facilities, we applied. At about the same time a special University Grant Program was introduced by Synercom, and we suddenly had their INFORMAP and EMIS packages operating on a GWS-IV workstation with a MicroVAX host within the department. Curricular changes were introduced to now present the Synercom conceptual model by means of demonstration of its operation, and assignments using its workstation. A new issue has arisen as expected, that a roomfull of workstations was needed to get a class of 40 onto the system in a meaningful way. We have not pursued this configuration for obvious reasons, but have arranged assignments in which groups of students resolve an applied problem using the system to overlay polygons.

GEOGRAPHERS IN G.I.S.

An unforeseen issue has also arisen. Perhaps as a result of familiarity with user-friendly microcomputing and mainframe environments, many students expect to gain understanding of G.I.S. and the operation of the GWS-IV workstation from free access to the departmental facility. Many have stated that they were expecting to gain operator-level skills in order to get a job in G.I.S. The course, however has stressed the functionality and utility of systems including Synercom's, in dealing with data conceptual models, graphic and non-graphic record structures, manipulation and analytical capabilities, output procedures, and applications. Expectations diverged considerably regarding the role of the Applied Geographer in G.I.S. It seems apparent that digitizing and other operator-level skills would enhance the entry of new graduates into the G.I.S. field, however their analytical and reporting skills - a more fundamental package of abilities - would be underutilized in the workplace if data entry

remained their primary responsibility. Introduction of workstation operation into the course has thankfully displaced material on the internal workings of computers, which appears to be well understood by most incoming first year students. What is more difficult to dispel, within both students and some employers is that facility in G.I.S. is not the same as workstation familiarity. A generic understanding of tasks, and their utility in problem solving applications are more typical of the talents Geographers bring to a job. With the proliferation of systems in the workplace, it is inconceivable that any university could train graduates to a working-knowledge level on all available systems. Education and training should be differentiated.

G.I.S. education should introduce students to the range of capabilities found in available systems. What is currently being marketed as G.I.S. includes an array of systems that vary considerably in their functionality, with many not fulfilling the evolving criteria for recognition as a "true G.I.S." Definition of what actually constitutes a G.I.S. continues to be the subject of discussion (Dangermond 1983, Cowen 1987, inter alia) though taxonomic criteria can readily be found for differentiating systems into classes (e.g. Tomlinson and Associates 1984, American Farmland Trust, 1985). Both the criteria, such as host C.P.U. environment, and the attributes of specific systems, such as the efficiency of certain algorithms, are extremely ephemeral. As examples: microcomputers may now have over 200 meg of storage and mainframes are available for the price of a mini; the raster/vector dichotomy must now accomodate quadtrees; polygons and topological overlay are being presented as components of systems previously lacking these functions. Continuation of these rapid changes in hardware and software products suggest there is little merit in acquiring a system for teaching purposes, but we have found it invaluable for demonstrating the intricacies of data capture, storage, manipuation and output, in the integrated environment which epitomizes a G.I.S.

DIFFUSION OF G.I.S. WITHIN THE CURRICULUM

It has become apparent that a single semester course is insufficient to develop all of the issues associated with G.I.S., even to a group who will primarily become system users. Not only is there insufficient room in our curriculum for additional course offerings specific to G.I.S., but arguments have been forwarded for dismissing this approach on pedagogic grounds. Goodchild (1985) suggests that G.I.S. is not really an area of specialization within Geography, but represents a fundamental

revision of the paradigm of the discipline. While not redefining our course offerings to accomodate this perspective, efforts have been made to acquaint students with G.I.S. principles in many quarters of the Applied Geography programme. This has not been difficult since computing has played a major role in our curriculum, and our applied perspective has kept faculty cognizant of the successes in our internship and graduate placements in G.I.S. Courses in which G.I.S. currently exerts a presence include:

Year 1 -Basic Research Methods - role of data, research paradigms, data quality issues, data sources
-Physical Geography - spatial features - points, lines, areas, coordinate referencing, geometric measures
-Computer Applications in Geography - hardware, programming languages, statistical packages
-Analytical Techniques I - spatial and descriptive statistics

Year 2 -Location Analysis - spatial modelling
-Analytical Techniques II - multivariate statistics
-Cartography - computer graphics and cartography, graphic and non-graphic records, workstation operations.

Year 3 -Resource and Environmental Planning Techniques McHarg overlays
-Internal Structure of the City -municipal information systems
-Retail Location - trade area analysis, analogue models
-Geographic Information Systems - concept of a system, digital representation of spatial information, geographic data entry, editing, storage, spatial analysis algorithms, output,
types of systems, topology, file structures,
application - site visits, user needs analysis, benchmarking
automation issues

Year 4 -Research Paper (thesis)

The current curriculum exposes students to computing in a variety of environments, from the decentralized network of remote ports into the academic mainframe , to workstations on the departmental Microvax, and graphic and non-graphic PC's. IBM's GFIS, GDBR and GDBA mainframe products are now being installed for inclusion in the winter semster of the G.I.S. course. Application has also been made to expand our departmental facilities to include a lab of micro-based G.I.S. workstations. Further refinement of the curriculum is envisaged to accomodate this new hardware and representative examples of the current array of software

products. Additional effort is being directed at enabling graduates to cope in an environment where programmers are not on site, and user support is primarily available via hotlines.

In closing, cooperative effort has contributed considerably to the successes encountered so far in our presentation of G.I.S. to Geographers. There are indications that similar successes are being realized at other universities (Maher and Wightman 1985, Aldrich 1987, Stevens 1987). From our perspective, three groups should be interacting more fully if G.I.S. is to meet its potential, and these are the universities, vendors and the user agencies. One recent survey (Nordisk Kvantif, 1987,13) has suggested a 4:1 payback on investment in spatial data bases shared among relevant organizations. Cooperation will provide a high profile for vendors'products, will improve the productivity of the user agency, and will promote relevance in the academic curriculum.

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STANDARDS

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GIS RESEARCH NEEDS IDENTIFIED DURING THE CARTOGRAPHIC STANDARDS PROCESS: FEATURES

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ABSTRACT

Between 1982 and 1987, the Features Working Group of the National Committee for Digital Cartographic Data Standards developed a cartographic features standard consisting of a model and definitions for Entities and Attributes. The results, while meeting the standards requirement, fell short in five areas. The purpose of this paper is to discuss the problems identified and suggest corrective research.

The refinement of existing definitions was needed. Specifically, the initial definitions have been "cleaned up" by making all the cross-references consistent and establishing the same kind of distinction between "main attribute terms" and "included attribute terms" that currently exists for entities.

Extension to other discipline areas is required. Currently limited to topographic maps and general nautical charts, the proposed standard features list of definitions must be extended to include other disciplines that regularly produce their own highly specialized maps.

Responsibility for maintenance has not yet been settled. The U.S. Geological Survey has the mandate for producing the standard, but the mechanism for maintaining it has not been established. Once initiated, a secretariat would provide the focal point for corrections, expanding feature definitions to other disciplines, and initiating an international standards dialogue.

Though tests were carried out for both "consistency" and "completeness" of the standard, they were limited in scope. A more thorough testing program needs to be developed and implemented.

Ambiguities are revealed in the proposed Model when dealing with individual features such as "Potomac River" and the members of the set that all have the same definition, such as "watercourse". The "feature"-"entity"-"object" relationship needs further clarification.

1. INTRODUCTION

The National Committee For Digital Cartographic Data Standards (NCDCDS) has, since its creation in 1982, developed a proposed standard, part of which concerned cartographic features. Working Group III (WGIII) was responsible for the features work and produced a Model consisting of entities, attributes, and attribute values and definitions for about 450 standard terms and 1200 included or cross-referenced terms. While meeting its original goals, there remained five specific areas that require additional effort. This is not to imply criticism of WGIII, whose hard work has been adopted in many foreign countries, but to identify problems and suggest corrective measures.

The five problem areas are: the refinement of existing definitions; extension to other disciplines; maintenance; testing; and ambiguities in the proposed Model of entity, attribue and attribute value. Each topic is discussed in detail and, where applicable, research directions are suggested. These new investigations will improve and maintain the standard, but will not substantially alter it.

2. REFINEMENT OF EXISTING DEFINITIONS

2.1 Process

Lists of feature terms were collected from GNIS, NOS, DMA and other sources of topographic and nautical chart information. The lists were divided up into categories (initially, "classes") such as hydrography, hypsography, culture, and land use. Cartographic elements such as contour lines, lettering and symbols were excluded from the lists because they were not features in the sense of real-world entities.

An individual was given responsibility for each category of features. Definitions were collected from numerous sources. Feature terms with similar concepts used in their definitions were lumped together into single feature categories. Any differences such as size or composition were provided for by attributes. Occasionally, this would require adding a new attribute term to the attribute list. The individual's compilation was reviewed by fellow staff members, and then by the Working Group, which assumed the role of a deliberative, decision-making body.

2.2 Collapse of Feature Classes

The initial "feature classes" were abandoned mid-way through the process. Several practical concerns led to this result. First, it was recognized that different agencies have different world views. A canal might be grouped with water features by one, while another regards it as a transportation artery. Second, a single term might have multiple meanings. For example, a "pass"

can be a mountain pass or a navigation lane. The definitions for such a term need to be compared with those in two or more different categories. Third, as the list grew, ease of reference became more important. A simple alphabetical list provided direct access to a given term, rather than the multistage search required through a classification hierarchy. Fourth, in the final review stage, it was necessary to consider the entire set of features, eliminating overlap and gaps between categories that had previously been reviewed separately. Once the initial list and definitions was established, a new feature term candidate needs to be reviewed in light of its potential impact on the existing set as a whole, including all features and attributes.

2.3 Review DMAFF

Simultaneously with the WGIII effort, the Defense Mapping Agency was working on a set of feature and attribute definitions called the DMA Feature File (DMAFF). The DMA adopted the rubric of features, attributes and attribute values, but with its own set of higher level feature classes. WGIII extended the proposed feature standard to include DMA features and attributes, except for purely military terms. WGIII also conducted a thorough review of DMAFF.

2.4 Testing

The proposed feature standard was initially tested in 1985-1986 for consistency, completeness, and ease of use. Four Federal agencies and four external organizations (a university and three private firms) participated in the test. The criteria of consistency, completeness, and ease of use were established by WGIII. Consistency meant repeatability: given the same list of terms and definitions, coders in different organizations looking at the same real-world feature would assign the same feature code. Completeness was recognized as a relative issue; the potentially universal set of defined features would never be "completed," but the Working Group wanted to know how well it had accomplished its intended task of defining the features shown on topographic maps and nautical charts. WGIII also wanted to know how the proposed standard might be received. In this regard, an important issue was how difficult or easy the standard would be to use. These three criteria were built into a simple test, taking on the average a person-day to complete.

The test consisted of three parts. The first part, the "consistency" test, involved coding features from the same source document (a topographic quadrangle) into standard categories. The second part, the "completeness" test, involved translating USGS and NOS topographic and hydrographic legends into standard features and attributes. The third part, to evaluate "ease of use," was a series of open-ended questions about the other parts of the test and about the standard as a whole.

Test results are presented in detail in NCDCDS Report #7 (1986).

In general, WGIII concluded that the proposed standard represented a viable approach, with consistency and completeness scores on the order of 90%. The main problem noted was "too much flipping around" among paper documents; an on-line system for cross-referencing and retrieving included terms, features, related attributes and the definitions and codes for all of these was clearly needed.

2.5 Cross-referencing

In the absence of an on-line system, the evolving set of feature and attribute definitions developed loose ends; for example attributes referred to feature terms that had been changed, or features pointing to attributes that had never been defined. In August 1987, software was written to validate all cross-references in the feature and attribute lists: between "included" terms lists for standard entities and attributes, and "see" references from included terms back to standard terms; and between "attribute" lists for standard entities and the "entity" lists given with standard attributes. A thorough update of both lists was completed, to eliminate loose ends in the cross references, in September 1987. The updated list will appear as a microfiche insert in The American Cartographer's January 1988 edition.

3. EXTENSION TO OTHER DISCIPLINES

The proposed feature and attribute lists are currently limited to entities appearing on general nautical charts and topographic maps. However, any spatially-related feature can be represented on a map. The prospect of a virtually unlimited number of unique features representing a wide spectrum of topics raises several questions. Is it desireable to include all of these features in our lists? If so, do standards exist in the applicable disciplines? Finally, will the existing organization of one universal listing of standard and existing terms work?

3.1 Desirability

The effort required to collect and standardize all mappable feature terms would be immense. Would it be worthwhile? Specialized mapping is frequently undertaken by the discipline involved for its own audience of practitioners and customers. Would they gain by having their unique features added to thousands of other unrelated terms? Possibly not; however, there might be two significant advantages. The first would be in interdisciplinary mapping. With the growth of computer use, more previously independent data are being combined and displayed. The huge urban data banks of cadastral, planning, utility, transportation, and other topics is one example. Another might be the paleontologist showing the interrelationships of ancient fauna, landscapes, and climates. Exchange and utilization of disparate data would certainly be greatly facilitated by

published standard terms. The second argument for combining would be to aid cartographers in their efforts to show thematic data effectively. Many disciplines turn to cartographers for final publication of maps appearing in books and atlases. The availability of standard terminology would benefit the product, and ultimately the reader, through superior classification of map data and more meaningful legends.

3.2 Existing Standards

Among the many topics mapped, how prevalent are standards of terminology? A quick sampling of a few selected disciplines produced the following results:

aeronautical charts - standardized, most terms already in list

demographic mapping - Census Bureau glossary is defacto standard

geology - standardized terms in AGI Glossary of Geology

hydrology - same as geology above

land use/cover - recommended terminology from five Federal land management agencies in negotiation

soils - Soil Conservation Service classification system is the standard

utilities - no existing standards

The presence of some standards is encouraging, but the adapting of certain hierarchal systems to the proposed Model may not prove easy.

3.3 Integration

Supposed everything were combined into one "super" list. Would it work? The resulting list would be very long and tedious to use in printed or microfiche form. But if placed in a relational data base and accessed by computer, usage would be greatly simplified. Another problem would be the integration of new terms having multiple meanings. Usage may need to be indicated.

4. MAINTENANCE

4.1 Background

The Memorandum of Understanding negotiated between the National Bureau of Standards and the U.S. Geological Survey in 1980 designated the USGS with the lead responsibility for developing, defining, and maintaining data elements and standards for earth

science information systems. Cartographic data standards were a part of the broader requirement and responsibility for that aspect was assumed by the National Mapping Division (NMD). To effect the widest possible participation, the Division elected in January 1982 to organize and fund the NCDCDS under the auspices of the American Congress on Surveying and Mapping. The NCDCDS WGIII produced the model and entity-attribute definitions for the Proposed Standard. Because of the dynamic nature of both technology and language plus the fact that only general nautical and topographic terms have been defined, it was recognized that there would be changes and additions. To address these future needs, an effort was made to define the maintenance requirements, create a mechanism for accomplishing the identified tasks, and to designate the responsible parties.

4.2 Requirements and Responsibilities

Five maintenance requirements were identified: responding to queries; deciding on proposed changes and additions; keeping the standard current; participating in international standards discussions; and publishing and distributing the standard. A Secretariat to answer queries, update the standard, and be involved internationally were assumed to be the responsibilities of the USGS under the terms of the original mandate. The fifth task of publication and distribution normally falls to the Bureau of Standards. The remaining decision chore is the largest and most complex. How could proposed corrections and additions to the terms be decided in a manner both representative of and acceptable to the involved parties? For example, who would referee differences between physiographic and nautical usage or coordinate the acquisition of new feature terms from other disciplines?

4.3 Mechanism

In 1947 the Congress enacted Public Law 242 that created the Board of Geographic Names (BGN) for the purpose of standardizing geographic names. The Act specified that the Board "shall provide for uniformity in geographic nomenclature and orthography throughout the Federal Government." The responsibility for geographic nomenclature and its established decision mechanism representative of concerned Federal agencies attracted WGIII. BGN was approached on the possibility of creating a subcommittee to approve feature definitions, but voted against assuming this new responsibility. The final resolution of future maintenance responsibility has not been made.

5. TESTING

5.1 Whole Standard

The testing process described above was limited to the

cartographic features portion of the standard. Future testing will include all aspects of the proposed Spatial Data Transfer Specification including features, cartographic objects, transfer format, and data quality. Cartographic objects are conceptually the zero, one, two or three-dimensional sets of coordinate strings that specify the location of a feature. The transfer format selected for the standard includes a self-defining set of modules, records, fields and subfields to convey the meaning as well as the data from one system to another, within a framework for information interchange specified by the International Standards Organization (ISO/8211). Data quality concerns the lineage, positional accuracy, attribute accuracy, logical consistency, and completeness of the information being exchanged. Whereas the features standard has been tested by itself, the combined testing will examine how well the features scheme interacts with "cartographic object" constructs, how well it can be evaluated in terms of quality criteria, and how well all three aspects of the contents of a data transfer-- objects, features and quality-- are supported by the transfer format.

Another major difference in future testing will be to consider the "decoding" end of spatial data transfer. Until now, most tests, whether of features, objects, formats or quality have been concerned with getting data into standard form, rather than the equally important process of obtaining usable data from standard transmissions.

5.2 Criteria

The same criteria can be used for a test of the full standard as were used for the features test. These included consistency, completeness, and ease of use.

Consistency. Consistency in the larger context means that given the same set of data, two independent parties would arrive not only at the same features, attributes, and attribute values, but also at the same cartographic objects and quality information; and that all this information would be encoded in the same modules, records, fields and subfields of the proposed transfer specification. To design a test with so many variables is a difficult problem, but the goal of achieving consistency is crucial for the success of a standard.

Completeness. Completeness is a criterion for which results can be obtained more quickly and easily. Gaps are bound to surface in the process of converting any existing data into standard form and, especially, in converting back from the standard to an existing production environment.

Ease of Use. Ease of use is a matter of perception. One person's "simplicity" is another's "stupidity;" one person's "flexibility" is another's "complexity." There is an inevitable tension between a standard that is flexible enough to be used by most organizations, and one that any would find easy to use. The

proposed feature standard has been carefully prepared to receive and transmit information in a way that allows complete coverage of features to be transmitted, but avoids potential overlaps and inconsistencies in the application of the standard. Clearly, to adapt to such a system will require considerable effort, at least initially.

Additional criteria for a test of the full standard will include goals for successful decoding from standard to non- standard data. Such goals include, for example, preservation of meaning and reversibility.

Preservation of Meaning. The proposed standard is replete with definitions, particularly in the parts concerned with cartographic objects and features. A goal is to preserve meaning in the sense that the receiving party understands what has been transmitted in the same sense intended by the sending party. Some early attempts at data transfer foundered, for example, when it turned out that terms such as "location" and "coordinates" were not shared between exchanging parties, or the terms were used in common but with different definitions. Use of non-standard terms, or absence of needed terms, can readily be identified in the transfer process. Changes in nuance of meaning may be more difficult to detect, until a test is made for reversibility.

Reversibility. Consider the following situation. The Geological Survey has some data on roads in a locality. It transfers the data to the Census Bureau for use in the 1990 Census. The Bureau converts the information to its own format and uses it, but finds a new road that did not exist when the air photo was taken from which the Survey compiled the original data. The Bureau updates the data set, changes it back to Survey format and returns it to the Survey. This seems a straightforward process of data exchange.

Add to the situation that the exchange in both directions goes through a format used by neither organization, but agreed to by both as a standard. The exchange should work the same way. If the information comes back to the Survey and can be decoded to the same internal format in which it was initially prepared, without loss of meaning, the goal of reversibility has been achieved.

5.3 Support

Time and budget constraints will limit the level of testing that can be accomplished in the near future. Subsequent tests will rely on a reasonable system to support independent tests and to incorporate feedback as improvements in the standard. Such a system is likely to include a maintenance authority, ISO/8211 software, other support software, and a manual.

6. MODEL AMBIGUITIES

Several ambiguities have been encountered since the features standard was developed. These have surfaced in the process of interaction with other parts of the proposed standard and with other groups involved in the feature definitions process. Among the issues for future consideration are hierarchical implementations, entity vs. object, feature vs. feature instance, the concept of an attribute, attribute value definition, and authority.

6.1 Hierarchal Implementations

The user option of feature classes opens the door for something WGIII strove to avoid, a hierarchical scheme for defining features. Clearly, hierarchies are not a naturally occurring phenomenon, but reflect either the computer systems being used for feature coding, or the mind sets of those responsible for developing codes, or both. An ambiguity of the proposed standard is whether standard attributes might function as lower order branches in a classification tree. An attribute such as "land/water" was intended to distinguish, for example, between an airport for seaplanes and one for the land- based variety. If it were systematically applied to all features in a given set, it could define feature classes rather than an attribute of a particular feature.

6.2 Entity vs. Object

A fundamental ambiguity in the proposed standard is between real world features and their representation in a data base. A "cartographic object" is, by definition, a digital representation of a feature; however, the content of the standard definitions of "objects" is that they include only two kinds of information: coordinates and topology. Thus, an "object" such as a node or string does not represent anything but the location of a feature, and possibly the relationship of that location to the locations of other features. Location is viewed in the WGIII model as an attribute, not as the thing itself. A road is not represented in a data base by a line; it is represented as a feature "road" which has a location given by a line. The distinction becomes clearer if one considers the location of the same road being represented two ways: as an area between the edges of the pavement at large scale, and as a single line or linear symbol at smaller scale. The "cartographic object" has changed, but the real world phenomenon is still the same, and can be represented the same way, with all of its other attributes, in the data base.

6.3 Feature vs. Feature Instance

Several ambiguities surround the problem of distinguishing a set of features from the individual occurrences comprising the set. There is a difference between an instance of a feature (say, "New

York") and the feature category ("city") that is ignored in the WGIII model. This difference is exacerbated by the use of the term "entity" as an alias for "feature" in the standard. The term "entity" connotes a single instance of a feature, whereas the feature labels such as "road" and "railway," defined by WGIII, stand for all feature instances of the same kind.

The quality standard requires the use of standard codes for features where available, for example FIPS codes for counties. The problem is that the FIPS code applies not to the feature "counties," but to an individual instance of the feature, e.g. "Nelson County."

This problem does not exist in the same way for attributes. The WGIII model includes both a general attribute category ("attribute") and a specific instance ("attribute value"). Attributes (e.g., "name") apply to "features," and attribute values (e.g., "New York") to "feature instances." Unfortunately, there is not always a one-to-one correspondence between a feature instance and an attribute value. Consider a road, "Reston Avenue", that has an attribute "width." If the road narrows from four lanes to two lanes, is it still the same road? If so, how would the width be coded? If not, how is the information retained that both the four lane and the two lane sections are part of "Reston Avenue?"

In sum, it appears that the WGIII model should be expanded to include a concept of "feature instance." The concept of "feature instance" should be clearly defined and its relationship to "attribute value" specified. The current use of the term "entity" might have to be reconsidered in the process.

6.4 Concept of Attribute

The concept of "attribute" was assumed to be different from the concept of "feature" by WGIII, but the difference has not been elaborated. In common sense terms and as defined by WGIII, a feature is a thing itself and the attributes are characteristics of the thing. It is simply the difference between parts of speech. However, since attributes are often used in definitions, there is no clear dividing line between the attributes that belong to a feature definition, and the ones that should be kept separate in the attribute list. WGIII has suggested broad categories of characteristics that fit the concept of "attribute:" measure, serviceability, structure and composition. What analogous broad categories fit the notion of "feature?" Form and function have been suggested. Where is the dividing line between the characteristics included in feature definitions and those that should be defined separately as attributes? More research is needed to explore this issue.

6.5 Attribute Value Definition

A number of ambiguities surround the notion of defined attribute

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values. If the attribute is width and the value is given in meters, what is the definition of the value? First, the domain of the values is part of the definition. For example, the domain can be "positive values in meters to three decimal places," or "one of the following three categories: salt, brackish or fresh." If the domain consists of a list of nominal categories, they should also be defined: "brackish" is between 15 and 30 parts of salt per 1,000 parts of water.

A second problem is whether to allow multiple domains for the values of a given attribute. For example, salinity can be represented as "salt, brackish or fresh" but also as "parts salt per 1,000 parts water." Choosing one domain or the other for a standard would result in loss of information, but allowing a choice weakens the standard.

A third problem of attribute values is whether the definition should change according to the feature being measured. For example, road width might be measured from shoulder to shoulder, while railroad width might be measured from edge to edge of the right-of-way. The same general definition of "width" applies to both examples, but is it really the same attribute? Do all attributes need to be defined separately for each feature to which they apply?

6.6 Authority

The current draft proposed standard includes an "authority" subfield for entities, attributes and attribute values. This is another construct that was not envisioned by WGIII, since the expectation was that all features and attributes could be mapped to the standard. The "authority" subfield allows for non-standard entity and attribute terms to be used, and even for non-standard "authorities" to be cited. The existence of this subfield reflects ambiguity in the notion of a standard itself: is a standard simply a standard format for exchanging nonstandard information?

7. CONCLUSION

Of the five problem areas identified, one, the refinement of existing definitions, is being addressed and the results will be published in January 1988. The other four areas need attention. Support for this work is not on the horizon, but the effectiveness and adoption by users of the standard depends on undertaking the suggested research.

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GIS RESEARCH NEEDS IDENTIFIED DURING A CARTOGRAPHIC STANDARDS PROCESS: SPATIAL DATA EXCHANGE

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ABSTRACT

Three issues identified during the development of a U. S. national standard for spatial data exchange are presented. The first issue points out the need for a stronger spatial data modeling framework. The second issue identifies a need for more focus on spatial metadata description and management. The third is a call for more detailed investigations of spatial data transfer implementation strategies.

1. INTRODUCTION

As a result of work undertaken by the National Committee for Digital Cartographic Data Standards several research issues involving spatial data transfer have been identified. The issues as discussed in this paper are not limited to data transfer via magnetic tape medium, an immediate need for many organizations at the present time. Data transfer needs will soon surpass this stage as latent needs for access to information become voiced needs when the capabilities of more intelligent information management and data communications products are offered. The distinction between data retrieval in information management and data transfer to support database development will begin to blur when integrated and interoperable database environments (1) become available. Access to up-to-date information has always been a critical component of successful organizations, regardless of how it is done. Managing data, information and knowledge in an appropriate mix should continue to enhance decision making environments.

Three issues are described breifly in this paper. These are:

1. Spatial Data Modeling Framework
2. Spatial MetaData Description and Management
3. Spatial Data Transfer Implementation Strategies

Data modeling frameworks and metadata description are theoretical topics whereas data transfer implementation is an applied topic. Each topic is important by itself, and when taken in combination they are

even more important. The following justifications are given for the importance of these topics.

Multipurpose geographic information systems are becoming easier to use, but are also becoming more complicated in their design. As users' needs mature, they demand more from systems in terms of functionality and performance. We need to clarify our frameworks for data modeling such that we can characterize more of the complexity inherent in spatial data management, but do it in simple terms. Gaps between areas of study for spatial data modeling are not closing as fast as they should due to weak conceptual frameworks borrowed half-heartedly from other disciplines. Spatial data modeling for some problems is different than spatial data modeling for other problems. What is needed is a critical examination of why certain structures work bettter for the semantics of some problems than for the semantics of other problems. Such an examination can lead to a better understanding of the qualities of each strucuture and when it is appropriate to use that structure. Better frameworks can help us understand the interplay between problem semantics and structure. That is, how sematics may affect structure and how structure may affect semantics.

Federal, state, local and private organizations are producing volumes of spatial data at phenomenal rates. We are coming into an age of information overload due in part to data overload, but also because of our lack of knowledge to effectively manage information and data. This problem can be ameliorated by managing data about data in more effective ways than is currently being done. Data that describes other data is called metadata. Metadata management provides on-line access to metadata, rather than off-line access through external documentation.

As reported in the computer industry trade literature there is a growing concern that "...the fourth end-user revolution in computing has spawned a **network data movement crisis**" (2). More and more end users are demanding access to data that they can process with intelligent workstations, since workstation prices are dropping dramatically. A clear understanding of tradeoffs among spatial data transfer implementation strategies between computers are needed, as soon off-line data transfer will turn into on-line data transfer to meet information needs for timely decisions.

2. DATA MODELING FRAMEWORK

The three file structuring orientations developed as the heart of the data exchange standard in Report #8 (3) of the National Committee for Digital Cartographic Data Standards can be used as an example that points out a need to develop better frameworks. The three data structure forms are named: Object, Relational and Raster-Grid. The

basic question is "why these three?" The best answer is that the three alternatives are provided for convenience, simplicity and flexibility. The Object Form consists of modules that structure spatial object types in a traditional "record typing" manner where all data semantics pertaining to a particular object are stored together. The Relational Form consists of modules that store spatial objects as relations together with an appropriate set of operations. Several relations may be required to fully represent a spatial object type.

The Raster-Grid Form is used to transfer imagery data and grid cell data. Several iterations of definition were used to arrive at a set of raster-grid modules that can represent raster-grid data in a similar way.

The three data forms are at the second level of a three level framework for data description. The highest (first) level is a Conceptual Model of Spatial Data. The second level is a data structure. The third level is the implementation mechanism. The rudiments of the data description framework have been borrowed from work in database management concerning data model descriptions.

What is needed is a framework that helps clarify why each of the data structuring orientations is different. This should help with a more thorough understanding of the qualities of each and when it is appropriate to use each.

A few frameworks for spatial data modeling have been attempted. An early characterization of spatial databases in terms of levels of data organization appears in (4). The focus in that work is on stages of database design. A framework for spatial data using levels of data abstraction appears in (5). The data abstraction orientation originates in programming language research. Ilg (6) presents a spatial data model framework which attempts to synthesize several approaches for describing data levels.

Those characterizations attempt to provide a framework for understanding the structuring of spatial data. However, a framework for data structuring alone is not enough to describe data modeling. What is needed in addition to a description of structure is a description of basic operations on those structures, as well as a set of constraints under which those operations produce valid results. Structure, operations and constraints are the three basic components of a data model. Confusion with the 'data model' concept has lead to confusion with other concepts. Most notably, concepts involving levels of data organization, levels of abstraction, stages in database design, and levels of data description.

The concept of a "data model" needs clarification in the geographic information systems literature. Peuquet (5, p. 67) follows a definition provided by Ullman (7) which states that " a data model

may be defined as a general description of specific sets of entities and the relationships between these sets of entities." Martin (8) uses a similar definition: " A data model is a logical representation of the data structure which forms a database. It shows the data-item types and the associations among them." This interpretation of a data model is different than the one provided by Codd (9) who is responsible for the concept and has stated in (10) that a data model consists of three components: a collection of object types, a collection of operators and a collection of general integrity rules. A definition provided recently by the ANSI Database Task Group (11) is consistent with the definition provided by Codd. The ANSI Group defines a data model as "a set of concepts for describing the contents of, and constraints on a database, and a set of operations for changing the contents" (11, p. 56). The difference between "a specific set of entities" and "a set of concepts for describing " is that the former refers to semantic types of instances in a database whereas the latter refers to the constructs and operators that make up the data language for manipulating those semantic types in a database. The data model is thus the framework by which a data language is implemented, rather than how the database is implemented as implied by Ullman (7). A data language makes a database operational and consists of a data definition language (DDL) for defining schemas, a data manipulation language (DML) for manipulating data defined by that schema and a query language (QL) that embeds DML opertions for end users to manipulate the database.

An effective database design process consists of four major stages. The stages are: requirements collection and synthesis, conceptual view specification, logical modelling, and physical modelling (12, 13). A database design process relies on two orthogonal dimensions of data description (11). Each dimension is composed of several levels that characterize what is being designed. The phases of a design process should not be confused with the different levels of the data description. As a matter of practical design activity, database design almost always requires multiple data models in the design process.

The data description dimensions are point-of-view and intension-extension. These levels coexist simultaneously in a database implementation. That is, all levels exist at once to make a database operational. Levels of description along each of the dimensions do not coincide with the phases of database design on a one-to-one basis. Thinking that they do, or not distinguishing between the perspectives has resulted in some confusion in the database design literature in general and more confusion in the spatial database design literature specifically. Although software engineering concepts can be used to examine levels of data abstraction as in (5), one must remember that programming languages are different than database management system data languages. The concepts come from different foci in the literature: software engineering and database management. Although the two areas can contribute significantly to

each other (14), a failure to clearly distinguish the origins of the two literature orientations results in overlapping terminology that creates further confusion.

Some current research is focusing on a way to provide a single data model rich enough to capture almost all meaning for specification, design and implementation. Thus, such a data model could be the basis for both a conceptual specification language as well as the database programmming language (15, 16, 17). Such formulations are extensions, clarifications and implementations of semantic data models developed as a result of the inability of the classical data models to express semantics sufficiently. However, even the most robust of data models probably will not and should not be able to capture all the semantics of all problems. Otherwise, database management systems would be the same as application programs, reminiscent of the 1960's. The purpose of applications development is to supplement the generalized constructs in a database management system with special semantic constructs and/or operations (18). A DBMS is first and foremost an access mechanism, not an application program.

Certain description levels can be associated with certain stages in the database design process even though the data description levels in both the point-of-view and intension/extension dimensions are not related to the stages in a database design on a one-to-one basis. Conceptual modeling can be associated with the conceptual view and is the step concerned with detailing the specification of a database. Logical modeling is associated with the external view and represents the second step in the design process. An external view of a database application must be implemented in some database management system before a user can actually perform work. Physical modeling can be associated with an internal view representing an implementation stage of a database.

The field of spatial data management will continue to grow in an undirected manner until we come to an understanding of the characteristics by which to describe spatial data management systems with the same rigor as traditional data management systems. If we do not then we will continually be reinventing large application programs than use spatial data rather than inventing spatial data management systems.

3. METADATA DESCRIPTION AND MANAGEMENT

The success of a spatial data transfer in many instances relies on data that describes data. Data that describes data is called metadata. Many times databases are not useful beyond the original scope of a project because of the lack of documentation. Data are less useful as information when data describing database production conditions are forgotten and/or misplaced.

The circumstances described above exist because we have not made it easy enough to capture and manage spatial metadata. At any given time, an organization may need to know the "nature" of a database. The "nature" of a database is provided by metadata that can provide an understanding about the semantic or syntactic characteristics of data. Since metadata appears to be secondary to the primary purpose of capturing data, it can not be expected that such secondary data will be managed well, unless the task of dealing with metadata is made easier.

There are two thrusts to the metadata problem. The first concerns an identification and characterization of what metadata are important. The second concerns the constructs, operations and constraints used to perform metadata management.

Some important types of metadata are data quality, data structure types, and data meaning. Types of spatial data quality (3) are: positional accuracy, lineage, attribute accuracy, temporal accuracy, logical consistency, and completeness. More and more sources are being used to create databases. Each element in a spatial database has the potential of being at a different level of accuracy.

Semantic categories are implemented with different types of structures, such as point, line and polygon. A change in scale might necessitate a change in data representation. On-line access to changes in these representations can make for more flexible feature representation.

A lack of ways to manage data dictionaries for on-line retrieval of data meaning is a problem. The number of different sources of digital data from which one can retrieve data are increasing. With more databases it becomes difficult to use the meaning of data in a consistent manner. This is particularly true in the context of relational database management since much of the semantics of the data are stored in the minds of users and created at run-time.

Research in metadata management dealing with integrated data dictionaries is a step closer to more intelligent systems. In this respect it could be a step closer to intelligent data transfer. How far can one go in terms of describing the nature of a set of digital data such that no communication between parties is necessary? Knowledge-based systems to implement information resource dictionaries like that proposed in (19) could provide a start.

4. DATA TRANSFER IMPLEMENTATION STRATEGIES

The third issue is the way in which data transfer is implemented. Data transfer implementation can be considered a part of a long term

strategy for information access in an organization. The strategy is determined in large part by an organizations's institutional needs and requirements. The requirements can be stated in terms of a set of characteristics that describe the nature of the transfer as indicated by an information plan. Those parameters can be compared against a set of configuration parameters inherent in possible data transfer solutions. The comparison might indicate that a one time project-based transfer is warranted, in which case off-line data interchange would suffice. In another case, the comparison might indicate that multiple transfers are needed, requiring frequent transmissions over a communications line. Yet in another situation the need may be so frequent that a data management approach might be required that supports record level transfers rather than file-oriented transfers commonly used in the two previously mentioned environments. All of these environments require some form of conectivity for implementation.

Connectivity is defined as the ability to have two host computers participate in data communications. Connectivity possibilites can be examined in terms of data model similarity, coupling and data package granularity.

A data model environment could be homogeneous or heterogeneous. A homogeneous environment is one in which all data models are of the same kind. A heterogeneous environment is one in which data models are different, requiring data structure translation. Gallagher and Salazar (20) have shown that data structure translation can be a costly activity in a heterogeneous environment as opposed to a homogeneous environment. Much more work in heterogeneous environments is needed (11).

Performance, i.e. the speed of communications between systems, is determined by coupling. Coupling involves the mechanism by which systems consisting of hosts and their respective software components are interfaced in a communicating environment. A loosely coupled implementation environment is less costly than a tightly coupled environment. When a transfer environment is loosely coupled the data communications might be by off-line magnetic tape transfer, or electronic transmission over a modem. When a transfer environment is tightly coupled one database management system is connected logically to another (in terms of information content) and a hardware link usually is dedicated for high performance.

An ISO-8211 (21) implementation supports both on-line and off-line data transfer in a loosely coupled environment. ISO-8211 is a data descriptive file approach, where descriptive data is sent with the database to describe the structure of the information. Because this is a file oriented approach it may have some difficulty supporting rapid data transfers of data packages of differing sizes, as might be needed in satellite data collection.

According to the ANSI/X3/SPARC database management system (DBMS) Reference Model Report (11), tightly coupled database management systems of the same kind running under similar operating systems in a retrieval only mode, are the only environments well understood. All other environments are still research oriented. The advantages and disadvantages of integrated versus interoperable environments are still being investigated (1).

One major problem is that the DBMS reference model and open systems interconnection (OSI) reference model ISO-7498 (22) need some rethinking for a distributed environment. The reason is that the DBMS reference model and the OSI reference model are not framed within the other, but are mutually co-exisitng models for systems architecture. The systems services shared between the two architectures is not integrated appropriately in the models (11).

Coupling can be examined at several layers of the DBMS and OSI models. With tightly coupled systems the communications can take place at any time, initiated from either host. With loosely coupled hosts the communication must be requested - causing the activation of certain software sessions on the respective hosts. Another dimension of coupling that has yet to be researched to any extent is application coupling. That is, the ability for communicating programs to understand the nature of the communications such that a decision about sophisticated processing can take place without continual input from humans.

Another aspect of connectivity is granularity. Granularity is the bundling of constructs into information packages. Granularity can be coarse as in large packages such as databases, and fine as in small packages such as data fields. Whatever the degree of granularity, each package of information has a conceptual, logical and physical design interpretation.

Packages of information at a conceptual level refer to the bundling of information to describe a set of geographic features and their respective attributes as in a feature class or a specific geographic feature and its atttribute values. The conceptual interpretation is the meaning that the package has in an organizational context, e.g. a subject database or application database environment (8).

Packages of information at a logical level are constructed of logical files (alsc called virtual files in the data communications literature) consisting of logical records. Part, one or more logical records could be associated with a feature. Logical records consist of fields, and fields consist of subfields.

Packages of information at the physical level are constructed of bytes of a certain length packed into physical records. A physical record could consist of part, one or more logical records.

Another connectivity characteristic is whether a system is closed or open according to security classifications. Many private organizations maintain systems which are as secure as military systems. The proprietary nature of information requires special security controls to insure the secrecy of information for the protection of competitive advantage or privacy.

Each of these connectivity characteristics needs to be examined in more detail in regards to its affect on data transfer with large, geographically dispersed, spatial databases.

5. CONCLUSION

Thus paper presents a broader focus on the topic of spatial data transfer than is normally done. This broad focus covers spatial data modeling, metadata description and management, and data transfer implementation strategies. When taken together, these three topics are the basis of spatial information integration, a topic currently under investigation by the author in the context of multipurpose geographic information systems used by local governments.

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GIS RESEARCH NEEDS IDENTIFIED DURING A CARTOGRAPHIC STANDARDS PROCESS: CARTOGRAPHIC OBJECT DEFINITION AND MANIPULATION

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ABSTRACT

A number of research needs have been identified in the area of spatial objects during the work of developing a set of national cartographic data exchange standards for the United states. These needs lie in the area of expanding digital spatial object definitions and extending the set of spatial operators. This paper is a call to the research community to focus more effort on these problems.

1. INTRODUCTION

During the past six years the National Committee for Digital Cartographic Data Standards has worked to develop standards for spatial data bases and associated exchange mechanisms for the United States. During this process efficient definition of an object standard was hampered on a number of occasions by gaps in cartographic and spatial knowledge that impeded the work of the Committee. This paper deals with a systematic presentation of the more obvious research needs relating to the definition of spatial objects that were identified during this process. The initial scope of the effort was defined by Moellering (1) with the most recent version of the objects being defined by (2). The research needs discussed here go beyond the work of standards development because in many cases standards strive to systematically codify knowledge that already exists. This paper calls for the extension of current work and the development of new knowledge. It is motivated by the desire to further develop conceptual and theoretical work in geographic information systems and in analytical cartography. The following discussion is cast into two basic sections: the first on better definitions of an expanded set of spatial objects, while the second deals with the manipulation and use of spatial objects.

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2. OBJECT DEFINITIONS

The current standard specifies 0-, 1-, and 2-dimensional objects. This work has been reviewed by Moellering (3). This effort has been hampered by efficient approaches to define surfaces, the absence of modular three dimensional definitions of objects, and the lack of a comprehensive set of BNF definitions of the objects.

2.1 Extended 2-Dimensional Object Definitions

The first place where two dimensional object definitions should be expanded is to develop a comprehensive representation of a surface. With the current standard a surface can be built out of sets of the other zero, one and two dimensional primitives. For example, most standard Digital Terrain Models (DTMs) are built out of a set of points that are located in some systematic way. It is possible to construct an isarithmic representation of a surface out of linear objects such as strings, chains, rings or perhaps links. Surface representations can also be constructed from various kinds of polygons such as triangles to construct a Triangular Irregular Network (TIN) or perhaps a square cellular representation.

Since a surface is based on variations on the equation $Z=f(X,Y)$, it seems that a direct representation of a surface as a primitive object may be advantageous. There are several known approaches which with more work could perhaps be developed into surface primitives. These approaches could be specified in discrete or continuous formulations. The discrete surface could use regular or irregular structures, while the continuous surface could use some sort of global parametric specification or perhaps some sort of localized patch specification. The possibility of other parametric specifications should be explored with the ideal result being one comprehensive surface primitive that covers all cases. Short of the ideal specification would be separate specifications that cover the continuous and discrete cases separately. Each of these two specifications would cover all cases in its respective domain. Although a two case solution would not be as elegant as a single solution, it would be a significant step towards the specification of a meaningful surface primitive.

A second arena for extended research for two dimensional objects exists with pixels and grid cells. Currently pixels and gridcells are specified as geometry only objects. These current definitions ignore topology. It is clear that vector data structures have greatly benefited from the integration of topological properties of

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connectivity and contiguity, it seems possible that a similar benefit might be feasible for pixels, gridcells, and the special case of raster data structures. The addition of topological properties to pixels and gridcells might facilitate the more efficient use of these objects in spatial data structures. It is even possible that the topological property could help to more efficiently solve the raster-vector conversion problem if a more efficient data structure homeomorphism could be identified. Such work could lead to additional hybrid raster-vector data structures that might work more efficiently than current vaster data structures.

2.3-Dimensional Definitions

The definition of three dimensional spatial objects was not included in the current U.S. standard. This is because there was a strong feeling on the part of the Committee that too little was known about such objects and how an efficient set of primitives might be specified. Volumetric objects are important to analytical cartography and geographic information systems. Currently almost all work that uses 3-D objects builds them up from lower dimensional primitive and simple objects. Although this classic strategy works fairly well, it is very desirable to have a clearly specified set of three dimensional objects. This need is becoming even more important in view of the fact that many systems are now providing more direct methods for manipulating and displaying such objects.

Now is a very opportune time to conduct basic research into the direct specification of a comprehensive set of three dimensional objects using coordinate triples that will work both in Euclidean and simple curved coordinate systems such as a sphere or an ellipsoid. Currently the only real candidate is that of a prism that is a simple trapezoidal solid. Other candidates must be developed with more research. Cognate research areas as computer graphics and pattern recognition are grappling with the same problem (4,5,6). Although much of the work is being conducted in a piecemeal fashion, the development of the Initial Graphic Exchange Specification (IGES) has been rather systematic. Therefore there is great hope that more direct research will be conducted in GIS and cartography on three dimensional spatial objects.

2.3 BNF Definition of Objects

The Backus-Naur Form (7) is a very concise way of specifying the production rules by which spatial objects are

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formed. Since the structure of this notation is very general, they can be used to specify not only spatial objects, but also data structures and many other things. Some of the spatial objects proposed in the national standard are specified in BNF notation (2, pp. II 12-13, II 62, II 86-89), but the set has been only partially done. More recent work by the Digital Cartographic Data Standards Task Force (DCDSTF) has further developed the notation for the other spatial objects in the Draft Proposed Standard.

However the BNF notational form should be used as an analytical tool to suggest gaps or where logical extensions could be made to the object set, especially for pixels/gridcells, surfaces and three dimensional objects. Given the call for further research in these areas, the BNF definition structure offers the possibility of a rigorous logical tool that could be of great assistance to the research task at hand.

3. MANIPULATION AND USE OF SPATIAL OBJECTS

Once the family of spatial objects is more fully defined, one can consider a wider family of manipulations that can be conducted on such objects. This could be accomplished with an expanded set of spatial operators, more work in the topological domain, and work in hyperspace.

3.1 Expanding the Set of Spatial Operators

One should consider developing more fully the family of spatial operators that work in zero, one two and three dimensions. Of these, the one and two dimensional operators are perhaps the best developed. Zero dimensional operators are somewhat developed, especially if one assumes that they are point samples from a continuous surface. In some sense continuous surface operators can be considered as 2 1/2 dimensional operators while three dimensional operators in GIS and analytical cartography are practically unknown. However, some very interesting work has been done by Claire and Guptill (8), and Tobler (9) among others. What one would like to see is a periodic table of spatial operators that specifies them by dimension, scaling of the data, and perhaps other properties.

3.2 Topological Operators

Basic concepts of topology have been known and used in GIS

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and cartography for almost two decades. These concepts are well enough understood as topological applications in cartography that Corbett has published a monograph (10) on the subject. This work has not received sufficient recognition in the spatial sciences. Further work by White (11,12) has shown that topological operations are extremely helpful in a cartographic context. This work suggests that it may be possible to develop a set of topology only operators for spatial objects and data structures. Bouille (13, 14) has shown that hypergraph linkages in data structures are not only useful, but preferred for certain kinds of data structures. His Hypergraph Based Data Structures (HBDS) and the principles that they are based on are very helpful to efficient database design.

3.3 Hyperspace Operators

To date most work in the spatial sciences has confined itself to the three physical dimensions of human space. However, it is possible to conceive of a data space that has many more dimensions. This is not a space directly specified by the data structure as shown above by Bouille, but a data space that has to do with the attributes of the spatial features that are being coded and analyzed by spatial systems. Currently, it is easiest to analyze such a feature space in a parametric setting, but work in spatial cognition has shown that analysis of nonparametric space is also possible given certain constraints. Multidimensional classification of pixels in parametric space is fairly common in remote sensing. What is being suggested here is that similar kinds of analyses could be performed in spatial feature space. This space would have parametric measures, but work in nonparametric space is possible if little explored in GIS and analytical cartography.

4. CONCLUSIONS

The work of developing the U.S. national standard for spatial and cartographic data exchange has entailed a systematic exploration of the research work that related to it, including spatial object definitions. It turns out that during this systematic exploration of prior research many gaps in our knowledge and understanding were detected. The major research needs that have evolved from this work are extending the 2-D object definitions to include surface definitions, including 3-D object primitives, developing BNF definitions of these object primitives, expanding the set of spatial and topological operators in

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a systematic way, and finally, exploring the possibility of developing hyperspace operators. All of the research needs discussed here are clear research opportunities in GIS and analytical cartography.

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MEASURING THE QUALITY OF GEOGRAPHIC DATABASES

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ABSTRACT

The demand for systematic measurement of the quality of geographic databases is increasing as the use of digital geographic data expands. The Geographic Information System technology user should require levels of confidence or figures of merit to be issued with a digital database. In the absence of such measures practitioners have expended considerable effort to evaluate the quality of third-party supplied digital data. Many times publicly available data are discarded as a source because of a lack of documented quality indicators or because the data were developed for a non-related application. Even with the well intended endeavors of federal, state and local agencies and private industry to distribute spatial data the end users remain ravenous for quality data for a range of applications. Few data sets have universal appeal. As a result, technologists continue to develop customized databases of limited value to potential peer users because of variation in resolution and data aggregations. The positional, temporal, and factual quality of a data set should be evaluated with a series of quantitative repeatable and auditable standard quality measures. These methods will be useful to determine bias and the presence of systematic and random errors which may have been introduced during the construction of the database. This paper presents a framework for measuring the positional, temporal, and factual quality of geographic databases in terms of precision, accuracy, completeness, representativeness, and comparability of the data.

1. DISCUSSION OVERVIEW

This discussion presents a potential methodological model that may be applied by those who commonly use digital geographical databases constructed by other government agencies or private companies. The approach is designed to be sufficiently flexible to be modified given cost or schedule constraints. This discussion first addresses why users are compelled to measure quality;

second, presents cartographic generalization which is the foundation of the data portrayed in a digital database; and third, provides a description of quality assurance measures.

2. WHY MEASURE QUALITY

Fundamental to the appropriate application of digital geographic databases is the measurement of quality. Many have applied measures of accuracy as a singular indicator of quality. However, what constitutes accuracy? Errors can occur as a result of both systematic and random events. These errors can be characterized as factual, positional, temporal, and areal measurement in nature.

Users of digital geographic databases have many shared concerns regarding the inherent quality of source data. These include the method of collection, the cartographic generalization guidelines applied, and the overall reliability of the data. This discussion presents a methodological framework for measuring the quality of geographical databases. The framework is commonly applied in the physical sciences and has served the author as a valuable conceptual model to approach the analysis of error and eventually quality.

In recent years there has been a great deal of effort applied toward developing standards for geographical database construction. Every user of maps has questioned the validity of the source material. The same is true of those who use digital data sets. The end user is quite dependent on the developer of the digital data. Data preparation methods are currently not standard and are not likely to be such in the near future. Many times cost of development and intended application will influence, to a large degree, the inherent quality of a data set.

3. CARTOGRAPHIC GENERALIZATION

Various forms of cartographic generalization occur during the construction of digital geographic databases. To a large degree these are second generation generalizations in that the source has already been designed as a representation of the real world. Not all generalizations are systematic or repeatable; this should cause some concern on the part of the end users of such databases. Quality issues relating to precision, accuracy, completeness, representativeness, and comparability of the data all are affected by the degree of generalization.

Since a map is a reduced representation of the surface features, the scale of the map largely determines the amount of information which can be stored either graphically or as attributes. The consequence of scale reduction is generalization; the smaller the scale the greater the degree of generalization. Information contained in the map has two components, location and meaning. Generalization affects both (1). In the context of the digital geographic databases, cartographic generalization is the collective modifications made during map preparation and automation. Methods of generalization include selection, simplification (elimination), combination, exaggeration and displacement, and classification. The results of each of these methods can affect an end users satisfaction with a given database. For features which possess areal extent such as soils and land use, a minimum mapping unit is typically applied. These, however, may be too detailed or too general for the end users application. The classification of data sets many times presents a perplexing problem to applications specialists due to the frustrations of information loss.

4. QUALITY ASSURANCE MEASURES

Quality assurance measures are commonly used by physical scientists to isolate biases in sampling, modeling and related analytical methods. Most common are those methods which yield quantitative, repeatable measures of the precision, accuracy, completeness, representativeness, and comparability of a data set. These measures are intended to provide adequate confidence that a data set satisfies user requirements. The same methodological constructs can be applied to digital geographic databases.

Typically, constrained by rigorous cost and schedule requirements, users forego the effort of measuring quality and use a given geographic data set with a level of uncertainty. This uncertainty has lead many a user to misinterpretations and erroneous calculations. Many other users do some level of accuracy assessment but neglect to appreciate the lineage of the geographical data set.

A vendor quality assurance program is typically designed to measure the success of quality control. However, an end user must research beyond quality control and examine more closely the cartographic generalization guidelines which influenced the development of the product. Precision, accuracy, completeness, representativeness, and comparability are discussed below.

4.1 Precision

Precision is the degree of mutual agreement among individual data sets made under prescribed conditions in terms of position, factual entry or temporal validity. For example, two digital technicians, after an identical training program, can be instructed to capture the same set of point data with the same equipment and yield different results. The measured precision then is the variation between technicians. Precision can be quite useful in the identification of systematic error.

4.2 Accuracy

Accuracy is the measured degree to which the recorded value matches the true or referenced value. Bias is typically a measure of accuracy expressed as difference between a sample average and the true or referenced value. Acquisition of true or even reference values is sometimes difficult in geographic database. Point data sets most easily lend themselves to an accuracy measure. Point data bias measures may aid in the detection of a systematic error with hardware or digitizing methods in either an x or y direction.

4.3 Completeness

Completeness is the degree to which all intended entries into a database have been encoded and/or digitized. Omissions of data do occur and in some cases erroneous entries can be made. Measures of completeness can be simply expressed as a percentage complete by data element category.

4.4 Representativeness

Representativeness is many times an elusive measure even for the most experienced statistician. Representativeness is the degree to which the recorded observation represents the study area or analysis area as a whole. Many times sample plots are used to characterize a large area without a measure of representativeness. Selected measures of representativeness should be considered only after considerable forethought due to cost and logistic concerns. Soil and vegetation geographic databases are examples of data sets which may require a high cost to measure representativeness of detailed sample plots.

4.5 Comparability

Comparability is the degree to which a database can be merged with others covering the same geographic area or containing similar thematic data sets of adjacent areas. This is especially a concern for users of multitemporal and multiscale data which has been prepared by different entities.

5. RESEARCH IMPERATIVES

Many research opportunities exist for users of geographic digital databases. These opportunities range from revisiting mapping and database fundamentals to expanding the horizons of spatial statistics. Professions who use the databases have only just begun to evaluate data quality. Applications staff need to be trained to routinely measure data quality and to understand and, where appropriate, compensate for error. Errors of methodological origins may merit the greatest attention. Systematic errors will always exist in geographic databases; either by design or by unintentional means during the database construction and updating processes. The challenge of practitioners is to isolate and mitigate errors. Standardization of digital geographic database formats and quality may provide some relief. However, be careful, there are a lot of data available from third party sources which at first review may appear to meet an intended application but under detailed inspection may increase the uncertainty of a desired result.

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